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Costs of Remedial Response Actions at Uncontrolled Hazardous Waste Sites

SCS Engineers
Long Beach, CA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

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COSTS OF REMEDIAL RESPONSE ACTIONS AT UNCONTROLLED HAZARDOUS WASTE SITES

by

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Contract No. 68-01-4885

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16. ABSTRACT

The primary purpose of this study was to update conceptual design cost estimates for remedial action unit operations portrayed in earlier reports.

Thirty-five remedial action unit operation conceptual designs, addressing uncontrolled landfill or impoundment disposal sites, were costed for Newark, New Jersey, as well as for U.S. lower and upper cost averages within the contiguous 48 states. Such estimates were in terms of mid-1980 dollars.

Total component capital costs and operating costs were estimated for each unit operation. Total and average life cycle costs were computed. One example was presented to show how to estimate the costs of complete remedial response scenarios.

This report was submitted in fulfillment of Contract No. 68-01-4885 by SCS Engineers, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from April 11, 1980, to February 18, 1981, and work completed as of April 13, 1981.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (PL 96-510) provides for immediate attention to mismanaged and uncontrolled hazardous waste facilities. Section 105 of the Act requires revision and republication of the national contingency plan which was originally prepared and published pursuant to Section 311 of the Federal Water Pollution Control Act. The revision establishes procedures and standards for responding to releases of hazardous substances, pollutants, and contaminants, including methods for evaluating the relative costs for remedying any releases or threats from facilities which pose substantial danger to the public health or the environment. This report provides preliminary estimates of engineering costs for remedial action operations at uncontrolled landfill and impoundment disposal sites. It is intended for use by engineers and officials responsible for implementing remedial response actions in a cost-effective manner.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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SECTION 1

INTRODUCTION

BACKGROUND

Congress passed "Superfund" legislation in 1980, which authorizes EPA to assist in the elimination of uncontrolled waste sites through remedial response/cleanup actions. The responsible offices within EPA have requested the Office of Research and Development (ORD) to collect and provide technical information to support this program.

As part of that information collection process, remedial response cost data from earlier reports needed to be reviewed, revised, and presented according to a consistent computational framework. It is in response to that need that this project was undertaken.

OBJECTIVES

The objectives of this study were to review and update remedial response conceptual design cost data from earlier reports, to enhance such conceptual designs so that each constitutes an independent remedial response activity, and to integrate this cost data into a consistent methodology so that costs of such activities can be readily estimated and compared. Additional goals were to determine the relative influences which geographic price differentials and scale economies have on such estimates, and to provide a methodology for combining costs from the various remedial actions into complete scenarios of site cleanup. It is recognized that the accomplishment of these additional goals is only partially obtainable under a conceptual approach, and that further refinements will rely on subsequent research into the actual costs of real-life cleanup operations.

APPROACH

The technical approach for this project was divided into four tasks:

- Collect and review existing pertinent reports.
- Evaluate and refine conceptual designs.

- Estimate costs of conceptual designs.
- Estimate costs for an example remedial response scenario.

Although a considerable body of literature addresses some aspect of hazardous waste, the approach taken in the first task was to identify those source documents which provide a conceptual design approach to costing discrete types of cleanup activities for pollution problems at uncontrolled or abandoned sites. For the purposes of this report, these discrete types of cleanup activities are termed remedial response "unit operations." Although other documents were consulted, the primary sources for this type of information were:

- A. W. Martin. Guidance Manual for Minimizing Pollution from Waste Disposal Sites.
- The Fred C. Hart Associates. Technology, Prevalence and Economies of Landfill Disposal in the United States, Volume II.
- Geraghty and Miller. Surface Impoundments and Their Effects on Ground Water Quality in the U.S.
- JRB Associates. Remedial Actions for Waste Disposal Sites: A Decision Makers Guide and Technical Handbook.

The second task required that earlier versions of unit operation conceptual designs be evaluated with respect to the completeness of their component requirements, and the extent to which they represent discrete remedial activities. Deficiencies thus identified were to be corrected by revision of the component requirements for each unit operation. Scale economy considerations were addressed in this task, first, by defining the affected landfill and impoundment sites in terms of five scales of operation, and, second, by estimating unit operation component requirements which correspond to each scale of site operation. Size and quantity of components required to implement each unit operation were therefore estimated in terms of five different site sizes.

The third task estimated the component costs for each scale of each unit operation, and adjusted these cost estimates to reflect the most likely or typical variations due to geograhic price differentials. The emphasis in this costing process was to apply a consistent costing methodology which would allow later comparison and combination of unit operation cost estimates.

The fourth task showed how the discrete unit operations could be combined to estimate costs for complete remedial response "scenarios." This approach involves summing unit operation cost estimates.

REPORT ORGANIZATION

This report begins with a conceptualized description of the sites requiring cleanup (for site profiles, see Sections 3 and 4), provides generalized discussions of the various unit operations and the costing methodology (Sections 5 and 6), gives a detailed discussion for each of the 35 unit operations (Section 7), shows an example of how the cost estimates may be combined for costing complete remedial response scenarios (Section 8), and discusses the impacts which prices of major components can have on scale economies and regional variations in life cycle average costs. Appendix A provides a matrix of the components that appear in each unit operation (Table A-1); summarizes lower and upper average costs for each unit operation (Tables A-2 and A-3); and gives unit prices for all capital and O&M components (Tables A-4 through A-7).

QUALIFICATIONS AND LIMITATIONS OF RESULTS

The overall objective of this study was to estimate the cleanup costs of hazardous waste sites using a conceptual design approach. This approach was necessitated by the fact that "Superfund" remedial response activities are still in their infancy, and that real-world feedback on the cost of these hazardous waste cleanup activities is largely unavailable.

In using these cost estimates, the reader should exercise considerable caution. Cost estimates are only as complete as the unit operations they describe, or as realistic as the various assumptions and site profiles upon which they are based.

A subsequent volume to this report will use real-life experiences in actual hazardous waste site remedial actions to refine this volume's costing methodology.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The literature review verified that little has been done in estimating the cost of hazardous waste cleanup at uncontrolled or abandoned sites. Those sources which addressed remedial responses frequently followed a case study or national, industry-wide approach; cost information, if provided, was too highly aggregated for costing separate remedial unit operations. Those sources which did develop cost estimates at the unit operation level frequently omitted critical components or allowed substantial overlap in the scope of each unit operation. This study has attempted to overcome such deficiencies, as well as to quantitatively bound the effects which scale economies and regional price differentials are expected to have on the costs of implementing 35 different remedial response unit operations.

The primary product of this study has been a costing methodology which was consistently applied to each of these unit operations. The resulting cost estimates would seem to lend themselves readily to (1) comparing costs for alternative unit operations which perform the same function, or (2) computing combined cost estimates for unit operations which comprise a complete remedial response scenario. The problem with the first type of use is that such simple cost comparisons do not address technical differences in the capabilities or efficiencies of alternative unit operations which accomplish the same goal. Such differences depend on both the inherent configuration of each respective unit operation, and the environmental setting under which it is actually implemented.

As comprehensive as the site profiles may be, they still represent a conceptual design of an environmental setting, and are no substitute for actual site conditions when choosing among alternative unit operations. A subsequent report may expedite some of these qualitative considerations.

The problem with the second type of use is that the simple addition of unit operation costs, when configuring a complete remedial response scenario, ignores both real-world influences on conceptually derived costs and the minor joint effects of scale and agglomerative economies. More specifically, some scale economies may still be enjoyed when multiple unit operations all require similar component inputs. Agglomerative economies resulting from minor component overlap or redundancy may also occur when unit operations are combined into remedial response scenarios. Subsequent research should address these considerations.

Because complete remedial action scenarios for uncontrolled sites typically consist of several unit operations, much remains to be done, even from a conceptual design cost perspective, in identifying the most appropriate short- and long-term remedial scenarios. Such an effort might include a systematic evaluation to determine the most prevalent pollution problems occurring at uncontrolled landfill and impoundment sites. Once this set of "typical" pollution cases has been determined, likely remedial action scenarios could be configured using unit operations developed in this study. The resulting composite cost estimates for these scenarios could be configured using unit operations developed in this study. The resulting composite cost estimates for these scenarios could then be compared to determine the relative and absolute cost advantages of each alternative scenario.

SECTION 3

SITE PROFILE FOR REMEDIAL RESPONSE ACTIONS AT LANDFILLS

To determine the characteristics of remedial actions at landfill sites, five sizes of landfill disposal sites were hypothesized. Table 1 shows the assumed tons of hazardous waste contained in each of the five selected sizes.

The range in scale of the hypothetical landfill sites was developed primarily from two sources (2, 7), and the following assumptions were made:

- The surface area for each landfill is square.
- All landfills are cut and cover operations, with cut slopes at a 2:1 ratio and fill slopes at a 3:1 ratio.
- Operation at each landfill is 260 days per year for a 10-year period.
- The compaction rate is 0.596 tonnes/compacted m^3.

To help compare remedial actions for each scale of landfill operation, the following set of environmental conditions was assumed:

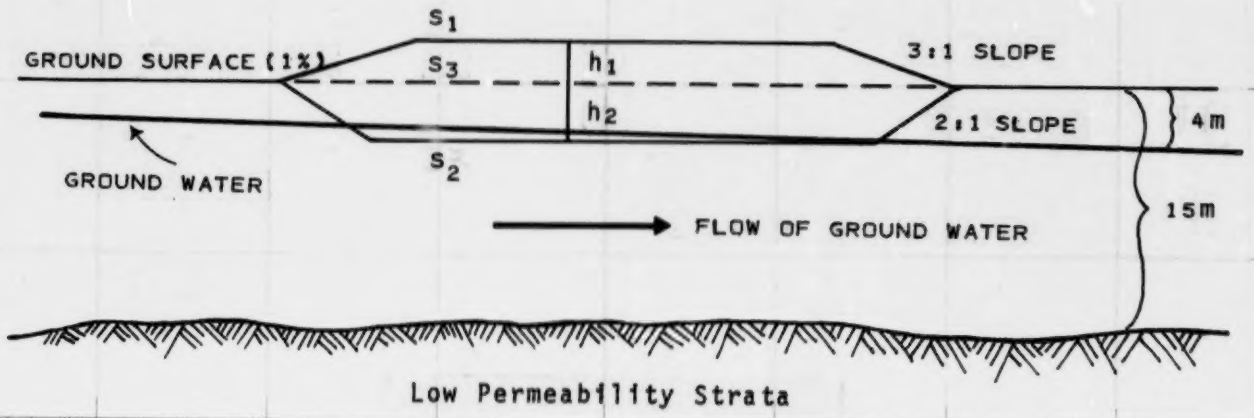
- Ground surface and ground water gradient are at a 1 percent slope.
- Ground water is 4.0 m (13.1 ft) from the ground surface.
- Low permeability strata ($<1 \times 10^{-6}$ cm/sec) is 15 m (50 ft) below the ground surface.
- Unconsolidated earth materials have a permeability of $\geq 1 \times 10^{-5}$ cm/sec.

It is recognized that no actual landfill will match the above-listed assumptions; however, these assumptions are necessary to develop conceptual costs later in this report.

TABLE 1. SIZE OF FIVE HYPOTHETICAL LANDFILL DISPOSAL SITES

Weight of Waste Material Contained		Volume of Waste Material Contained		Waste-to-Soil Ratio
Tonnes	Tons	m^3	yds^3	
24,000	26,400	40,000	52,400	1:1
120,000	132,000	200,000	260,000	1.5:1
240,000	264,000	400,000	520,000	2:1
700,000	770,000	1,200,000	1,570,000	3:1
1,200,000	1,320,000	2,000,000	2,600,000	4:1

Figures 1 and 2, respectively, show the typical side view and top view of the hypothetical landfill. With the design criteria established, and the environmental conditions at each landfill given, the dimensions for each of the five sizes of the hypothetical landfills are provided in Table 2.


S_1
GROUND SURFACE (1%)
S_3
h_1
3:1 SLOPE
h_2
2:1 SLOPE
4 m
GROUND WATER
S_2
FLOW OF GROUND WATER
15 m
Low Permeability Strata

Where:

T_L = Total volume of refuse (m^3)
D_L = Total volume of soil (m^3)
h_1 = Height of landfill above ground surface (m)
h_2 = Depth of landfill below ground surface (m)
S_1 = Top side of landfill (m)
S_2 = Bottom side of landfill (m)
S_3 = Side of landfill at ground surface (m)
A = Area of landfill at ground surface (m^2)

Figure 1. Typical side view of landfill.

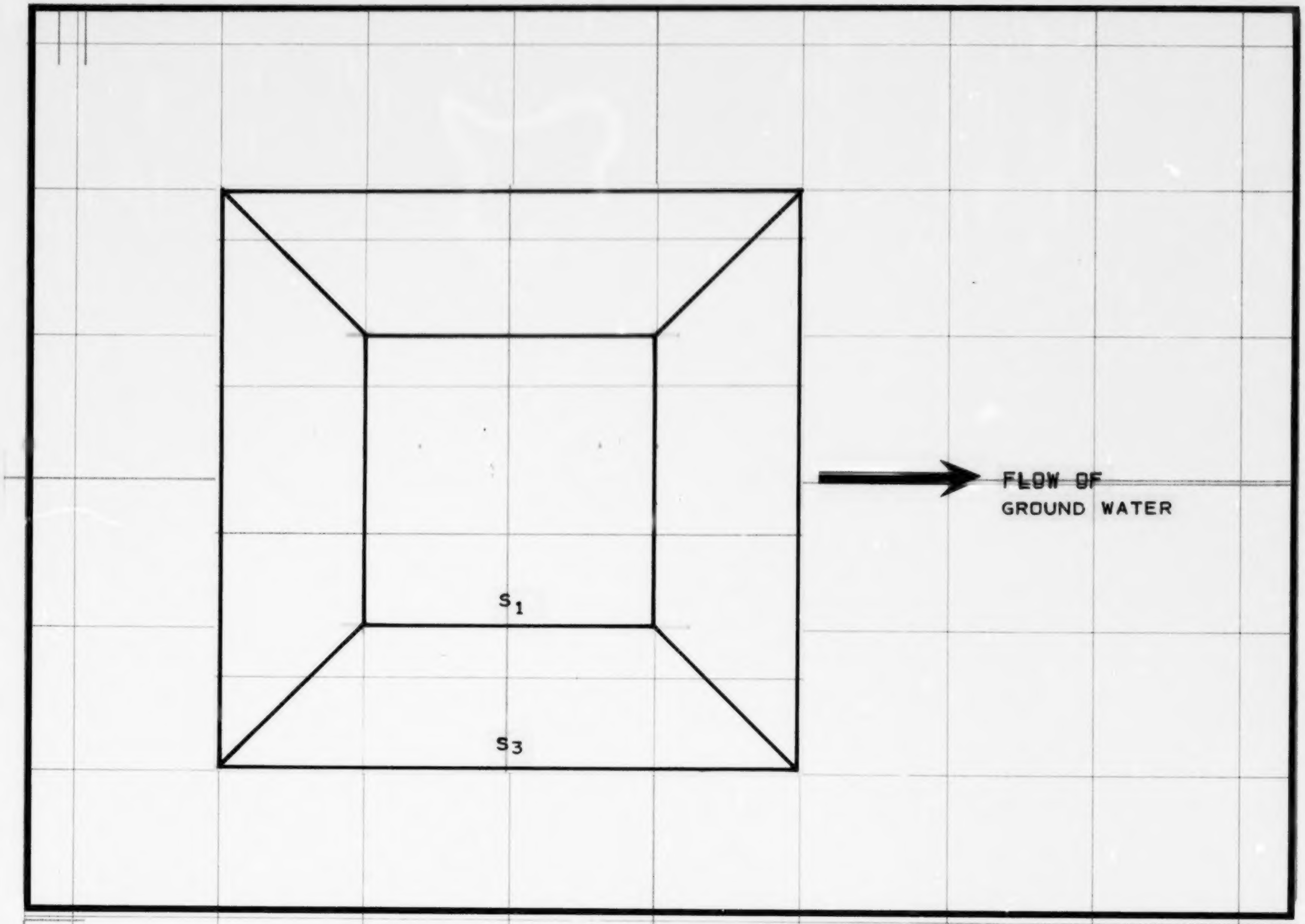

FLOW OF
GROUND WATER
S_1
S_3

Figure 2. Typical top view of landfill.

TABLE 2. SUMMARY OF LANDFILL DIMENSIONS*

Dimensions	Tonnes of Waste Material Contained in Landfill				
	24,000	120,000	240,000	700,000	1,200,000
T_L (m^3)	39,759	198,796	397,592	1,192,776	1,987,960
D_L (m^3)†	39,759	132,530	198,796	397,592	496,990
h_1 (m) #	6	7	8	9	10
h_2 (m)**	5	5	5	5	5
S_1 (m)	63.29	140.49	184.69	303.87	370.24
S_2 (m)	79.29	162.49	212.69	337.87	410.24
S_3 (m)	99.29	182.49	232.69	357.87	430.24
A (m^2)	9,859.0	33,303.0	54,146.0	128,073	185,108
A (acres)	2.43	8.23	13.38	31.65	45.74

* See Figures 1 and 2 for legend.

† Per waste-to-soil ratios; includes final cover.

# Assumed.

** Assumed; Note: bottom 1 m of landfill in ground water.

SECTION 4

SITE PROFILE FOR REMEDIAL RESPONSE ACTIONS AT SURFACE IMPOUNDMENTS

To determine the characteristics of remedial actions at impoundment sites, five sizes of impoundment sites were hypothesized. Table 3 shows the assumed waste influent volume and the assumed detention time for each of the five selected impoundment sizes.

The range in size of the hypothetical surface impoundments was developed primarily from two sources (3, 4). The sizes of the surface impoundments (area requirements and depth) were calculated from the flow and detention time requirements with varying depths. Based on these calculations, representative pond dimensions were chosen, consistent with impoundments of similar influent flows.

Although the scales of operation differ for each surface impoundment, the following criteria used to design the ponds are identical:

- The ponds are square and unlined.
- Berms are constructed from soils excavated during pond construction, and have 3:1 side slopes.
- Seven days per week (365 days per year) operation for 10 years.
- Sediment removed from pond bottom every 2 years.
- Wastewater contains 100 mg/l settleable solids.
- Density of solids is 2 g/cc.
- Sludge is 70 percent moisture by weight when removed.
- Wastewater is recirculated after allowing 3 to 10 days for solids settling.

TABLE 3. SCALE OF OPERATION FOR FIVE HYPOTHETICAL SURFACE IMPOUNDMENTS

Influent Volume of Waste		
M^3/Day	Gallons/Day	Detention Time, Days
10	2,640	3
50	13,200	3
500	132,000	10
5,000	1,320,000	10
50,000	13,200,000	10

- Because of short detention time and sludge on bottom, precipitation, evaporation, and percolation losses are considered negligible in volume calculations.

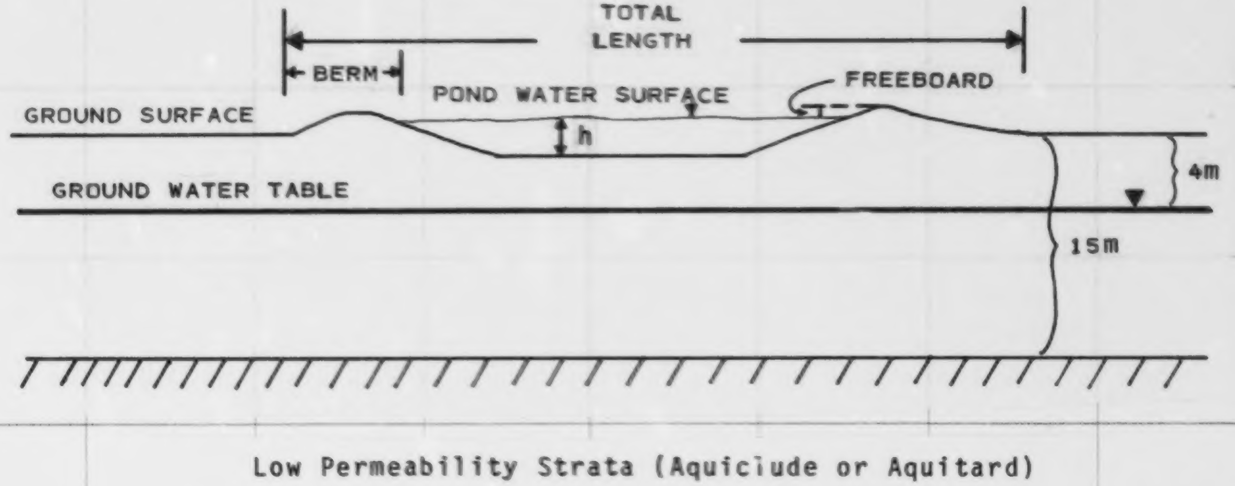
To help compare remedial actions for each of the scales of pond operation, the following set of environmental conditions was assumed:

- Ground surface and ground water gradient are at least 1 percent slope.
- Ground water is 4.0 m (13.1 ft) from the ground surface.
- Low permeability strata (aquiclude or aquitard) located at 15 m (50 ft) from ground surface.
- Unconsolidated earth materials have a permeability of $\geq 1 \times 10^{-5}$ cm/sec.

Figure 3 shows the typical side view of the hypothetical impoundments. With the design criteria established and the environmental conditions for each pond given, the dimensions for each of the ponds can be calculated.

Calculations for ponds were made as if ground surface were level, which does not affect the total surface area requirements of the impoundment structure.

Table 4 summarizes the dimensions for each scale of operation for surface impoundments.


TOTAL LENGTH
BERM
POND WATER SURFACE
FREEBOARD
GROUND SURFACE
h
GROUND WATER TABLE
4m
15m
Low Permeability Strata (Aquiclude or Aquitard)

Where:

- (Total length)^2 = impoundment surface area.
- Berm side slopes constructed at 3 horizontal to 1 vertical.
- Berm top width nominal 2 m, maximum 3 m.
- 0.5 m freeboard designed into all ponds.
- h = pond depth.

Figure 3. Side view of surface impoundment.

TABLE 4. SUMMARY OF SURFACE IMPOUNDMENT DIMENSIONS

	Cubic Meters Per Day				
Dimensions	10	50	500	5,000	50,000
Depth (m)	0.5	1.0	2.0	4.0	6.0
Berm top width (m)	2.0	2.0	3.0	3.0	3.0
Berm height (m)	0.5	0.5	0.5	1.5	2.5
Pond depth (m)*	0.5	1.0	2.0	3.0	4.0
Total surface area (m^2)	376.4	812.2	4,678.6	20,334.8	110,755.8
Surface water area (m^2)	88.4	342.2	3,181.0	15,525.0	95,357.0

* Below ground surface; maximum depth assumed to be 4.0 m.

SECTION 5

SHORT- AND LONG-TERM UNIT OPERATIONS

Table 5 lists the unit operations developed as remedial response actions for uncontrolled landfill and impoundment hazardous waste sites. These remedial actions can be characterized for each type of site under one of two response actions.

SHORT-TERM RESPONSE ACTION

A short-term response action was developed for sites where a temporary action can be implemented, and a quick response is necessary. The following points better define the characteristics of short-term remedial actions:

- Cost effectiveness of the remedial action utilized is less important than the expediency of the action.
- The remedial action results in a reduction in immediate hazardous as opposed to a permanent solution.
- Response time is short (weeks) and often in the early stages of site reclamation.
- Usually limited to small sites or equivalent portions of larger sites.

Of the remedial actions listed in Table 5, the following are considered to be short-term response actions:

- For landfills:
    - Well point systems
    - Chemical injection
    - Perimeter gravel trench vents.
- For surface impoundments:
    - Well point systems
    - Toe and underdrains
    - Leachate treatment

TABLE 5. LIST OF UNIT OPERATIONS USED AS REMEDIAL ACTIONS

Landfills

1. Contour grading and surface water diversion
2. Bituminous concrete surface sealing
3. Revegetation
4. Bentonite slurry trench cutoff wall
5. Grout curtain
6. Sheet piling cutoff wall
7. Grout bottom sealing
8. Drains
9. Well point system
10. Deep well system
11. Injection
12. Leachate recirculation by subgrade irrigation
13. Chemical fixation
14. Chemical injection
15. Excavation and disposal at secure landfill
16. Ponding
17. Trench construction
18. Perimeter gravel trench vents
19. Treatment of contaminated ground water
20. Gas migration control - passive
21. Gas migration control - active

Impoundments

22. Pond closure and contour grading of surface
23. Bituminous concrete surface sealing of closed impoundment
24. Revegetation
25. Slurry trench cutoff wall
26. Grout curtain
27. Sheet piling cutoff wall
28. Grout bottom seal
29. Toe and underdrains
30. Well point system
31. Deep well system
32. Well injection system
33. Leachate treatment
34. Berm reconstruction
35. Excavation and disposal at secure landfill

- Berm reconstruction
- Excavation and disposal at secure landfill.

LONG-TERM RESPONSE ACTION

A long-term response action for a hazardous waste disposal site consists of remedial actions that respond to problems which must be dealt with on a permanent, full-scale basis. Characteristics of long-term remedial actions include:

- Cost effectiveness.
- A significant hazard exists, but response times are on the order of months.
- Detailed site investigations and monitoring data are essential to defining the precise extent of the problem.
- The remedial action results in permanent closure of the site or long-term attenuation of the problem.

Based on the above definition, the following remedial actions are considered to be long-term responses to pollution problems:

- For landfills:
  - Contour grading and surface water diversion
  - Bituminous concrete surface sealing
  - Revegetation
  - Bentonite slurry trench cutoff wall
  - Grout curtain
  - Sheet piling cutoff wall
  - Grout bottom sealing
  - Drains
  - Well point system
  - Deep well system
  - Injection
  - Leachate recirculation by subgrade irrigation
  - Chemical fixation
  - Excavation and disposal at secure landfill
  - Ponding
  - Trench construction
  - Treatment of contaminated ground water
  - Gas migration control - passive
  - Gas migration control - active.
- For surface impoundments:
  - Pond closure and contour grading
  - Bituminous concrete surface sealing

- Revegetation
- Slurry trench cutoff wall
- Sheet piling
- Grout curtain
- Grout bottom seal
- Deep well system
- Well injection.

ALTERNATIVE UNIT OPERATIONS

When a pollution problem is identified, various unit operations can be used singly or in combination to control the same type of contamination. The following describes the type of pollution problem to be controlled, and provides a list of unit operations which may be used either in combination or as alternatives for each other.

1. For elimination of contaminated site runoff, the prevention of precipitation from entering a landfill or closed impoundment, the following are conjunctive/ alternative unit operations:

    - Contour grading and surface water diversion
    - Surface sealing
    - Revegetation
    - Berm construction/reconstruction.

2. For minimization of leachate formation, the following are conjunctive/alternative unit operations:

    - Contour grading and surface water diversion
    - Bituminous concrete surface sealing
    - Grout curtain
    - Sheet piling
    - Slurry trench
    - Deep well system
    - Well point system
    - Chemical fixation.

3. For the control of leachate/contaminated ground water migration, the following are conjunctive/alternative unit operations:

    - Grout curtain
    - Grout bottom seal
    - Sheet piling
    - Slurry trench
    - Well point system
    - Well extraction

- Well injection
- Toe and underdrains.

4. For gas (methane and other volatile hydrocarbons), the following are conjunctive/alternative unit operations:

   - Perimeter gravel trench vents
   - Gas migration control - passive
   - Gas migration control - active.

SECTION 6

COST COMPILATION METHODOLOGY

OVERVIEW

To estimate remedial action unit operation costs, it was first necessary to define each unit operation in terms of its intended use, its configuration with respect to the landfill or surface impoundment site profiles, the extent to which it may be used in conjunction with other unit operations, and all other pertinent assumptions. The referenced sources were of considerable assistance in developing this description.

Once this conceptual description was completed, the next step was to determine unit operation component requirements, and their associated costs, for the median scale at which the landfill or surface impoundment site profiles were portrayed. The resultant unit operation conceptual designs were then costed at the component and subcomponent levels using the price lists (Tables A-4 through A-11). This process involved identifying labor, equipment, material, and transportation requirements (i.e., subcomponents) for each component of each unit operation conceptual design. All costs so developed were in terms of mid-1980 dollars for the example location of Newark, New Jersey, as well as for U.S. lower and upper cost averages within the contiguous 48 states. The price lists thus provided a means of first identifying and then costing subcomponent requirements, as well as a tool by which regional cost variations were systematically included.

After the price lists were completed, conceptual design capital and operating cost estimates were accumulated, allowances for overhead and contingencies were applied, and total and average life cycle costs were computed. These life cycle cost averages were in terms of the units (by hectares of site size, m^3 of site volume, etc.) which best typify each unit operation.

USE OF PRICE LISTS

The price lists were developed to itemize material, labor, and equipment costs for each of the components used within a unit operation. For the most part, the 1980 Means and Dodge Guides were used to obtain the costs needed. The source unit prices shown on these price lists (Tables A-4 through A-11) were derived from the Dodge or Means quotation by presenting their estimate in terms of metric and English units.

Regional adjustment indexes presented in the Dodge Guide were used to modify the metric versions of Dodge or Means estimates for geographical differences. These indexes were applied to obtain revised material and labor costs for the U.S. Low, U.S. High, and Newark, New Jersey, estimates. No such index was available for equipment costs, so it was assumed that equipment costs are the same nationwide. Because the Dodge Guide and Means present costs differently, adjustments were made so that the regional indexes could be used for both sources. For example, in the Means, labor costs were not identified as a separate entry, but were included as part of installation. Thus, whenever the Means was used to present costs, the Dodge Guide Regional Adjustment Index for Labor was applied to installation costs.

Frequently, both Dodge and Means did not itemize costs into categories of labor, material, and equipment, but simply presented a "total" estimate. Depending upon which reference was used, the following rules were applied: In the Dodge Guide, if only a total cost was presented, an average labor/material index (assuming 50 percent material and 50 percent installation) was applied to the unit cost; in the Means, the "total" costs include an overhead allowance of 25 percent. This allowance was removed before the labor/material index was applied. In all cases, any cost entered in the shopping list was adjusted so that overhead allowances were not included.

The cost of each component presented in the unit operation conceptual design cost tables typically includes the sum of costs for any material, labor, or equipment subcomponent. These total costs for each component do not include overhead and contingencies. Once all the components within a unit operation were costed, they were summed, giving a subtotal capital cost for the unit operation. This subtotal capital cost was then used to obtain an overhead allowance (always 25 percent), and a contingency allowance (between 10 and 40 percent, depending upon the extent to which component requirements can be precisely estimated for each unit operation). The subtotal capital cost was summed with the overhead, and contingency allowances to obtain the estimate of total unit operation capital cost.

LIFE CYCLE COSTING

Once total capital and operating costs were determined for lower and upper U.S. and Newark locations, total and average life cycle costs were computed to ensure that any subsequent cost comparisons of unit operations could be equitably accomplished.

Although unit operation O&M cost estimates are for 1980, as the first year of operation, component quantity requirements were determined so as to be adequate for each of the first 10 years of the remedial operation. This attribute of the conceptual designs means that the 10-year life cycle evaluation of operating costs was only required to address subsequent inflation and appropriate discounting of these O&M component costs to their mid-1980 present values. It was further assumed that capital costs would not be amortized and discounted, but would be considered as fully incurred in the first year of operation. As a result of these assumptions, average annual compounding inflation rates for electricity and for all other O&M components were derived using estimates from the April 1980 Survey of Current Business (8). These inflation rates were derived as follows:

Type of O&M Input:	Electricity	All other O&M inputs
Related Published Cost Index:	Electric Power	Consumer Price (CPI-W)
March 1980 Index Value:	305.7	239.9
Average Annual Index Percent Increase Since Base Year (i.e., 12.75 years since mid-1967, when index equaled 100):	9.160 percent	7.104 percent
Assumed Future Inflation Rate:	9.2 percent	7.1 percent

It should be pointed out that a similar process was accomplished for estimating a fuel inflation rate, but that all unit operations were configured with only electrical equipment.

In determining the present values of future expenditures, the March 1980 Gross National Product Implicit Price Deflator (also published in the April 1980 Survey of Current Business) of 174.51 was similarly evaluated in terms of its 1972 base year to estimate an annual general inflation rate of 7.4 percent. To this, an assumed 4 percent social time preference rate was added to create a total annual discount rate of 11.4 percent. The life cycle cost methodology was then followed, in which inflated operating costs were discounted to their mid-1980 present values, and summed with total capital costs, to determine total life cycle costs over the 10-year life spans of the configured unit operations. Average life cycle costs were then computed by dividing this total by the number of units which best typify each unit operation.

SECTION 7

UNIT OPERATIONS

Tables 6 through 40 depict the remedial action unit operations portrayed in this study.

TABLE 6a. UNIT OPERATION 1. CONTOUR GRADING AND SURFACE WATER DIVERSION

Use: Contour grading of a landfill is accomplished by reshaping the land to promote and channel surface runoff.

Configuration: Surface water diversion involves excavating ditches and creating earth berms on the upslope side, directing drainways to the downslope of the landfill.

Conjunctive Uses: Commonly used with revegetation and gas venting.

Assume:
1. Soil excavated and graded at a depth of 0.5 m.
2. 0.3 m thickness of soil will be added to complete grading.
3. Diversion ditch extends halfway down each side of the landfill.
4. Borrow pit for excavating soil is adjacent to landfill.
5. Borrow pit for excavated soil is adjacent to site.
6. Soils used are well suited for final cover.
7. Diversion ditch is rebuilt two times per year after major storms.

TABLE 6b. COSTS OF CONTOUR GRADING AND SURFACE WATER DIVERSION FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation, Grading, and Recontouring of Site (27,685 m^3)	43,820	50,790	49,050
Excavation and Grading Soil (16,910 m^3)	15,190	17,720	17,090
Diversion Ditch Construction (180 m^3)	310	650	560
Capital Cost (subtotal)	59,320	69,160	66,700
Overhead Allowance (25 percent)	14,830	17,290	16,680
Contingency Allowance (15 percent)	8,900	10,370	10,000
Total Capital Cost	83,050	96,820	93,380
O&M Costs			
Maintenance & Repair Cost - Diversion Ditch (180 m^3)	620	1,300	1,120
Total O&M Cost	620	1,300	1,120
Total Life Cycle Cost (over 10 years)	88,280	107,780	102,820
Average Life Cycle Cost*			
Per ha	16,318	19,922	19,006
Per ac	6,598	8,055	7,685

* For a medium size site (5.41 ha).

TABLE 7a. UNIT OPERATION 2. SURFACE SEALING BY BITUMINOUS CONCRETE

Use: Surface sealing involves the construction of a seal (or cap) on the landfill to prevent water infiltration and to minimize leachate generation.

Configuration: Caps and seals can be constructed of clays, fly ash, bituminous concrete, membrane liners, lime, or cement.

Conjunctive Uses: Commonly used with contour grading and revegetation. Chemical fixation may be used if stabilized waste material is a sealing material.

Assume:
1. Seal complete for entire site.
2. Cost includes transportation and installation.
3. A 0.6 m soil cover will be placed over each surface seal.
4. Borrow pit for excavating soil is adjacent to site.
5. Subsidence potential is minimal.

TABLE 7b. COSTS OF SURFACE SEALING BY BITUMINOUS CONCRETE FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation, Grading, and Recontouring of Site (27,685 m^3)	43,820	50,790	49,050
Excavation and Grading, Soil (for contouring 16,910 m^3)	15,190	17,720	17,090
Surface Seal (55,364 m^2) Bituminous Concrete† Cap (0.08 m, 3")	168,590	244,990	216,560
Capital Cost (subtotal)	227,600	313,500	282,700
Overhead Allowance (25 percent)	56,900	78,380	70,680
Contingency Allowance (35 percent)	79,660	109,730	98,950
Total Capital Cost	364,160	501,610	452,330
O&M Costs			
No further maintenance needed (10-year life span before action needed).			
Total Life Cycle Cost (over 10 years)	364,160	501,610	452,330
Average Life Cycle Cost*			
Site Area			
Per ha	67,312	92,719	83,610
Per ac	27,217	37,490	33,806

* For a medium size site (5.41 ha).

† See price list for alternative surface sealing materials/installation.

TABLE 8a. UNIT OPERATION 3. REVEGETATION

Use: Revegetation helps to physically stabilize the earth material and reduce infiltration; it also serves to minimize erosion of the cover material by wind and water.

Configuration: Revegetation involves first grading the landfill, covering it with a suitable, fertile soil, adding soil supplements, and then seeding.

Conjunctive Uses: Contour grading, surface sealing, and gas migration control.

Assume:

1. Entire surface of landfill is revegetated.
2. 0.6 m of clay and silt loam will be used for landfill cover.
3. Clay and silt loam are easily accessible; transportation costs are not included.
4. Mulch will be used to stabilize soil until vegetation takes hold.
5. Native grasses will be used for seed.

TABLE 8b. COSTS OF REVEGETATION FOR MEDIUM SIZE LANDFILL

Capital Costs	Dollars Lower U.S.	 Upper U.S.	 Newark, NJ
Area Preparation (5.41 ha)	3,710	6,440	5,760
Excavation, Grading, and Recontouring of Site (27,685 m^3)	43,820	50,790	49,050
Hydroseeding (5.41 ha)	4,900	6,900	6,200
Mulching (5.41 ha)	1,450	2,080	1,860
Capital cost (subtotal)	53,880	66,210	62,870
Overhead Allowance (25 percent)	13,470	16,550	15,720
Contingency Allowance (10 percent)	5,390	6,620	6,290
Total Capital Cost	72,740	89,380	84,880
O&M Costs			
Grass Mowing (5.4 ha) (6 mowings/yr)	320	650	550
Refertilization (5.4 ha) (1 time per yr)	250	350	300
Total O&M Cost	570	1,000	850
Total Life Cycle Cost (over 10 years)	77,550	97,810	92,050
Average Life Cycle Cost*			
Per ha	14,335	18,079	17,015
Per ac	5,796	7,310	6,880

* For a medium size site (5.41 ha).

TABLE 9a. UNIT OPERATION 4. BENTONITE SLURRY-TRENCH CUTOFF WALL

Use: A slurry-trench cutoff wall is an underground barrier used to prevent leachate formation and horizontal subsurface movement of leachate.

Configuration: The process entails digging a trench, filling it with Bentonite slurry as excavation progresses, and backfilling with excavated material.

Conjunctive Uses: Contour grading and revegetation are commonly used. Surface sealing is used as well.

Assume:

1. Extend cutoff wall to low permeability strata (15 m).
2. Slurry is mixed 1 part Bentonite to 12 parts water.
3. Bentonite requirements are 0.039 tonnes/m^3 of trench.
4. Subcontractor has applicable license for slurry trench installation (all patented processes).

TABLE 9b. COSTS OF BENTONITE SLURRY-TRENCH CUTOFF WALL FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	3,850	6,520	5,720
Slurry Trench Excavation (10,800 m^3) (720 m (L) x 15 m (d) x 1.0 (w)) (Includes installation of Bentonite Slurry)	347,760	588,710	516,670
Bentonite, Delivered (419 tonnes)	27,830	74,200	69,570
Capital Cost (subtotal)	379,440	669,430	591,960
Overhead Allowance (25 percent)	94,860	167,360	147,990
Contingency Allowance (30 percent)	113,830	200,830	177,590
Total Capital Costs	588,130	1,037,620	917,540
O&M Costs			
Monitoring Sample collection (12 d/yr, 96 hr/yr)	760	1,570	1,370
Analysis - Primary & secondary parameters - 12 background/yr - 12 downgradient/yr 24 samples/yr	7,900	7,900	7,900
Total O&M Cost No maintenance is required	8,660	9,470	9,270
Total Life Cycle Cost (over 10 years)	661,900	1,117,450	995,690
Average Life Cycle Cost*			
Per m^2	61.22	103.47	92.19
Per ft^2	5.69	9.62	8.57

* For a 10,800 m^2 wall face at a medium size site (5.41 ha).

TABLE 10a. UNIT OPERATION 5. GROUT CURTAIN

Use: A grout curtain solution fills the voids in the soil and thereby minimizes or stops the flow of ground water and/or leachate.

Configuration: A grout curtain is created by injecting solutions or water/solid suspensions under pressure into soils and underlying earth materials as ground water barrier.

Conjunctive Uses: Contour grading and revegetation are commonly used. Surface sealing is used as well.

Assume:

1. Extend curtain to low permeability strata (15 m).
2. Used a two-row grid chemical grout; phenolic resin grout.
3. Injection points are on 1.6 m centers.
4. For injection, use a 5:1 water to chemical grout ratio.

TABLE 10b. COSTS OF GROUT CURTAIN FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Drilled holes - cased (test injection, prior to use. Cost includes excavating hole, installation of test well, and injection). 1 to 6" diameter hole (15 m)	235	400	350
Geotechnical Investigation	3,850	6,520	5,720
Grout Curtain (32,400 m^3). Cost includes excavation, injection (720 m (L) x 15 m (d) x 3.0 m (w))	6,479,900	13,050,400	11,388,800
Capital Cost (subtotal)	6,483,980	13,057,320	11,394,870
Overhead Allowance (25 percent)	1,620,990	3,264,330	2,848,720
Contingency Allowance (30 percent)	1,945,190	3,917,200	3,418,460
Total Capital Cost	10,050,160	20,238,850	17,662,050
O&M Costs			
Monitoring Sample Collection (12 d/yr) (labor rate) (96 hr/yr)	760	1,570	1,370
Analysis - Primary and Secondary Parameters ($330/sample) - 12 background/yr - 12 downgradient/yr 24 samples/yr	7,900	7,900	7,900
Total O&M Cost No maintenance is required over 10-year period.	8,660	9,470	9,270
Total Life Cycle Cost (over 10 years)	10,123,170	20,318,680	17,740,200

TABLE 10b (continued)

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Average Life Cycle Cost*			
Per m^2	937	1,881	1,643
Per ft^2	87	175	153

* For a 10,800 m^2 wall face area at a medium size site (5.41 ha).

TABLE 11a. UNIT OPERATION 6. SHEET PILING CUTOFF WALL

Use: A sheet piling cutoff wall is a physical barrier, which will lower the water table in and around the landfill so that the refuse is no longer saturated, and leachate generation is reduced.

Configuration: A sheet piling cutoff wall involves driving lengths of steel sheet piling permanently into the ground with a piledriving hammer.

Conjunctive Uses: Contour grading and revegetation may be used. Surface sealing is also used.

Assume:
1. Extend wall to low permeability strata (15 m).
2. Facility surrounded by piling.

TABLE 11b. COSTS OF SHEET PILING CUTOFF WALL FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Sheet piling (PMP-22) (1,162 tonnes)			
Cost includes construction, installation and shipping. (720 m (L) x 15.0 m (d))	526,850	776,700	686,300
Capital Cost (subtotal)	526,850	776,700	686,300
Overhead Allowance (25 percent)	131,700	194,170	171,570
Contingency Allowance (25 percent)	131,700	194,170	171,570
Total Capital Cost	790,250	1,165,040	1,029,440
O&M Costs			
No further maintenance is necessary.			
Total Life Cycle Cost (over 10 years)	790,250	1,165,040	1,029,440
Average Life Cycle Cost*			
Per m^2	73	108	95
Per ft^2	6.80	10.03	8.86

* For a 10,800 m^2 wall face area at a medium size site (5.41 ha).

TABLE 12a. UNIT OPERATION 7. GROUT BOTTOM SEALING

Use: Bottom sealing involves creating a bowl-shaped bottom seal beneath the site for the purpose of isolating the landfill from the ground water.

Configuration: The seal is constructed by pumping or pressure injecting grout under the existing landfill through tubes placed through the fill at regular intervals.

Conjunctive Uses: Contour grading and revegetation are commonly used.

Assume:
1. Use of an exploratory boring hole to test the strata below the landfill
    - 0.03 m (4 in) diameter holes
    - 30 m centers
    - extended 5.0 m below surface.
2. Grid on 2 m centers.
3. Cement bottom liner, 1.6 m thick.
4. Soil - 25 percent voids.

TABLE 12b. COSTS OF GROUT BOTTOM SEALING FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Exploratory Boring (930 m)	12,800	21,660	19,010
Material Testing (see Exploratory Prior to Installation Boring) 15 m deep - 4" diameter hole	210	400	350
Surveying (2 days)	310	520	460
Grout Curtain Bottom Seal ($83,046\ m^3$) a) Piping costs b) Material costs c) Shipment of materials d) Installation of pipe e) Labor	17,306,790	33,450,930	29,190,670
Capital Cost (subtotal)	17,320,110	33,473,510	29,210,490
Overhead Allowance (25 percent)	4,330,030	8,368,380	7,302,620
Contingency Allowance (40 percent)	6,928,040	13,389,400	11,684,200
Total Capital Costs	28,578,180	55,231,290	48,197,310
O&M Costs			
Monitoring			
Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis (24 samples)	7,900	7,900	7,900
Total O&M Costs	8,660	9,470	9,270
No maintenance is required.			
Total Life Cycle Cost (over 10 years)	28,651,190	55,311,120	48,275,460
Average Life Cycle Cost*			
Per ha	5,295,969	10,223,867	8,923,375
Per ac	2,141,345	4,133,865	3,608,031

* For a medium size site (5.41 ha).

TABLE 13a. UNIT OPERATION 8. DRAINS

Use: The purpose of drains is to intercept ground water and carry it away.

Configuration: Drains are constructed by excavating a trench, partially backfilling it with sand or gravel, placing a drain pipe in the sand and gravel bed, and completing the backfill.

Conjunctive Uses: Contour grading and revegetation are commonly used.

Assume:
1. Drains are used to channel and collect leachate to prevent sidehill seeps and seepage into surface water bodies.
2. Drain is sloped 2 percent downgradient to submersible pump.
3. Electrical service available.

TABLE 13b. COSTS OF DRAINS FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Trench Excavation (1,560 m^3) 260 m (L) x 6 m (d) x 1 m (w)	2,070	2,360	2,290
Gravel (1,050 m^3) (includes installation)	7,460	11,420	10,080
Cement Pipe, 4" (perforated) (260 m) (Cost includes installation)	1,510	2,420	2,130
Submersible Pump (1)	550	900	790
Drilled holes - cased (casing for sub pump) (7 m) 6" hole	110	180	160
Backfill Costs (510 m^3)	890	1,070	1,030
Capital Cost (subtotal)	12,590	18,350	16,480
Overhead Allowance (25 percent)	3,150	4,590	4,120
Contingency Allowance (25 percent)	3,150	4,590	4,120
Total Capital Cost	18,890	27,530	24,720
O&M Costs			
Monitoring Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis - Primary & Secondary Parameters - 12 background/yr - 12 downgradient/yr 24 samples	7,900	7,900	7,900
Because drains have a 10-year life span, no maintenance is necessary.			
Power cost (electrical)	100	100	100
Total O&M Costs	8,760	9,570	9,370

TABLE 13b (continued)

Capital Costs	Dollars Lower U.S.	 Upper U.S.	 Newark, NJ
Total Life Cycle Cost (over 10 years)	92,810	108,280	103,780
Average Life Cycle Cost*			
Per m	357	416	399
Per ft	109	127	122

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* For 260 m of drain pipe at a medium size site (5.41 ha).

TABLE 14a. UNIT OPERATION 9. WELL POINT SYSTEM

Use: Well point systems are used to lower the water table and/or collection leachate.

Configuration: Well points are placed upgradient to the landfill, and are connected to a suction header. The header is connected to a pump which evacuates the air from the well points and the header. This vacuum results in external pressure which forces the ground water to flow through the well points.

Conjuctive Uses: Contour grading and revegetation are commonly used.

Assume:
1. No leachate collects with ground water.
2. Pumping area upgradient from landfill.
3. Dewatering down 5 m.
4. Electrical service available.

TABLE 14b. COSTS OF WELL POINT SYSTEM FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Well Point System (1,010 m) (133 wells)			
Installation of Wellpoints and Wellpoint Fittings (Cost includes installation)	43,040	72,860	63,950
1,100-1,500 L/min centrifugal pump (1) standby centrifigal pump (2)	3,200	3,200	3,200
Discharge Pipe (300 m) (Materials and installation) 8"	12,770	22,110	19,390
Recharge Trench (1,650 m^3)	1,850	3,130	2,750
Header Pipe (400 m)	17,030	29,490	25,850
Geotechnical Investigation	3,850	6,520	5,720
Spread Excavated Material (1,650 m^3)	1,050	1,250	1,200
Sand (133 bags) (1 bag/well)	600	820	720
Capital Cost (subtotal)	83,390	139,380	122,780
Overhead Allowance (25 percent)	20,850	34,850	30,700
Contingency Allowance (25 percent)	20,850	34,850	30,700
Total Capital Costs	125,090	209,080	184,180
O&M Costs			
Monitoring Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis - Primary & Secondary Parameters - 12 background/yr - 12 downgradient/yr 24 samples/yr	7,900	7,900	7,900
Power Costs 36,000 kWh @ 40 hp (0.05/kWh) Pump runs 2,400 hr/yr	1,800	1,800	1,800
Total O&M Costs	10,460	11,270	11,070

Pumps have 10-year life.

TABLE 14b (continued)

Capital Costs	Dollars Lower U.S.	 Upper U.S.	 Newark, NJ
Total Life Cycle Cost (over 10 years)	214,580	305,400	278,810
Average Life Cycle Cost*			
Per m^2	107.29	152.70	139.40
Per ft^2	9.97	14.19	12.96

* For a 2,000 m^2 intercept face area at a medium size site (5.41 ha).

TABLE 15a. UNIT OPERATION 10. DEEP WELL SYSTEM

Use: Deep well systems are useful for dewatering soils in cases where a large vertical interval must be dewatered.

Configuration: Each well is equipped with its own pump.

Conjunctive Uses: Contour grading and revegetation are commonly used with deep well systems.

Assume:
1. Dewatering to 12 m.
2. Deep wells are 14 m deep.
3. Electrical service available.

TABLE 15b. COSTS OF DEEP WELL SYSTEM FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Dewatering System (13 wells) installed:			
Deep Wells (drilled/installed/cased) 14 m deep, 6" PVC (182 m)	2,670	4,570	3,960
1 hp submersible pump and wiring (13 pumps)	7,150	11700	10,270
Discharge Pipe (300 m) 4" PVC	6,270	11,560	10,100
Recharge Trench (1,650 m^3)	1,850	3,130	2,750
Geotechnical Investigation (includes exploratory boring, surveying, mobilization, drilling additives, pump test, report)	3,850	6,520	5,720
Spread Excavated Material (1,650 m^3)	1,050	1,260	1,200
Gravel for Recharge Trench (1,650 m^3)	11,710	17,950	15,430
Capital Cost (subtotal)	34,550	56,690	49,430
Overhead Allowance (25 percent)	8,640	14,170	12,360
Contingency Allowance (30 percent)	10,370	17,010	14,830
Total Capital Cost	53,560	87,870	76,620
O&M Costs			
Monitoring Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis - Primary & Secondary Parameters - 12 background/yr - 12 downgradient/yr 24 samples/yr	7,900	7,900	7,900
Power Costs 1,800 kWh @ 1 hp x 13 pumps - 23,400 kWh/yr ($0.05/kWh) pumps run 2,400 hr/yr	1,170	1,170	1,170
Total O&M Costs	9,830	10,640	10,440
Total Life Cycle Cost (over 10 years)	137,280	178,420	165,480

TABLE 15b (continued)

Capital Costs	Dollars Lower U.S.	 Upper U.S.	 Newark, NJ
Average Life Cycle Cost*			
Per m^2	28.60	37.17	34.48
Per ft^2	2.66	3.46	3.20

* For a 4,800 m^2 intercept face area at a medium size site (5.41 ha).

TABLE 16a. UNIT OPERATION 11. INJECTION

Use: Injection is used to provide a barrier to leachate movement.

Configuration: Water or leachate may be introduced through well points or deep wells. The leachate must either be attenuated on its new course and mixed with ground water to harmless concentrations, or discharged at some point where it causes no harm to the receiving water body.

Conjunctive Uses: Contour grading and revegetation are commonly used.

Assume:
1. Deep wells to make water barrier, placed downgradient.
2. Depth of barrier is 15 m.
3. Assume water supply present at site.
4. Electrical service available.
5. Interim measure; used for 5 years.

TABLE 16b. COSTS OF INJECTION FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Deep Wells, Drilled and Installed (13 wells 6" 14 m deep) (182 m)	2,670	4,570	3,690
Centrifugal Pump (13)	20,800	20,800	20,800
Geotechnical Field Investigation	3,850	6,520	5,720
Capital Cost (subtotal)	27,320	31,890	30,210
Overhead Allowance (25 percent)	6,830	7,970	7,550
Contingency Allowance (30 percent)	8,200	9,570	9,060
Total Capital Cost	42,350	49,430	46,820
O&M Costs			
Monitoring			
Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis	7,900	7,900	7,900
- Primary and Secondary Parameters			
- 12 background/yr			
- 12 downgradient/yr			
24 samples/yr			
Power Costs 4,032 kWh @ 3/4 hp x 13 pumps = 52,416 kWh/yr (0.05 kWh) (7,200 hr/yr operation)	2,620	2,620	2,620
Water Costs ($3.50/1,000 gal) 7,200 gal/pump/day x 13 pumps) (300 days of operation/yr) (Pump rate of 5 gpm is for costing purpose only)	98,280	98,280	98,280
Total O&M Costs	109,560	110,370	110,170
Total Life Cycle Cost (over 10 years)	967,870	981,780	977,490
Average Life Cycle Cost*			
Per m^2	1,760	1,785	1,777
Per ft^2	164.05	166.40	165.68

* For a 550 m^2 intercept face area at a medium size site (5.41 ha).

TABLE 17a. UNIT OPERATION 12. LEACHATE RECIRCULATION BY SUBGRADE IRRIGATION

Use: Once leachate has been intercepted, subgrade irrigation is used to spread the leachate over the landfill. This helps to decrease stabilization time.

Configuration: Subgrade irrigation uses perforated pipe lined in gravel-lined trenches.

Conjunctive Uses:

Assume: 1. Electrical service available.

TABLE 17b. COSTS OF LEACHATE RECIRCULATION BY SUBGRADE IRRIGATION FOR MEDIUM SIZE LANDFILL

Capital Costs	Dollars		
	Lower U.S.	Upper U.S.	Newark, NJ
Excavation of Drainage Trench (0.6 m wide, 1.0 m deep, with backhoe loader) (630 m^3)	1,830	3,280	2,840
Gravel - 3/4" (630 m^3) includes installation	4,480	6,860	5,880
Cement Pipe - 6"			
- Perforated (960 m)	7,780	12,040	10,610
- Non-perforated (90 m)	630	1,010	890
Deep Wells (drilled and cased) (6 wells) (14 m deep)	1,230	2,110	1,830
Submersible Pumps & Wiring (6 pumps)	3,300	5,400	4,740
Spread Excavated Material (630 m^3)	400	480	460
Capital Cost (subtotal)	19,650	31,180	27,250
Overhead Allowance (25 percent)	4,910	7,800	6,810
Contingency Allowance (20 percent)	3,930	6,240	5,450
Total Capital Costs	28,490	45,220	39,510
O&M Costs			
Monitoring			
Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis - Primary & Secondary Parameters - 12 background/yr - 12 downgradient/yr 24 samples/yr	7,900	7,900	7,900
Power Costs 1,800 kWh @ 1 hp x 6 pumps = 10,800 kWh ($0.05/kWh) (2,400 hr/yr)	540	540	540
Total O&M Costs	9,200	10,010	9,810
Total Life Cycle Cost (over 10 years)	106,440	130,000	122,600

TABLE 17b (continued)

Capital Costs	Dollars Lower U.S.	 Upper U.S.	 Newark, NJ
Average Life Cycle Cost*			
Per ha	19,675	24,030	22,662
Per ac	7,955	9,716	9,163

* For a medium size site (5.41 ha).

TABLE 18a. UNIT OPERATION 13. CHEMICAL FIXATION

Use: Chemical fixation relies on the reactions of cementation/setting/reactive agents (such as cement, lime, silicates, etc.) with the waste material, by the process of mixing. This application of chemicals is quite waste-specific, and is done to destroy or stabilize hazardous materials.

Configuration: Because the above method is too costly for most landfills, the configured alternative is to chemically stabilize only the upper portion of landfill waste materials for use as a cover.

Conjunctive Uses: Contour grading and vegetation are commonly used.

Assume:
1. Stabilized waste materials are not releasing toxic levels of pollutants.
2. No cost of obtaining stabilized waste material.
3. Only top 1/2 m of landfill is mixed with fixation agents.

TABLE 18b. COSTS OF CHEMICAL FIXATION FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavating, Grading, and Recontouring of Site (27,685 m^3)	34,970	41,940	40,200
Excavation and Grading, Soil (16,910 m^3)	15,190	17,720	17,090
Application of Stabilized Waste Material (33,218 m^3) (includes spreading and hauling)	183,320	381,200	331,730
Capital Cost (subtotal)	233,480	440,860	389,020
Overhead Allowance (25 percent)	58,370	110,220	97,260
Contingency Allowance (35 percent)	81,720	154,300	136,160
Total Capital Cost	373,570	705,380	622,440
O&M Costs			
Monitoring			
Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis	7,900	7,900	7,900
- Primary & Secondary Parameters			
- 12 background/yr			
- 12 downgradient/yr			
24 samples/yr			
Total O&M Costs	8,660	9,470	9,270
Total Life Cycle Cost (over 10 years)	446,580	785,210	700,590
Average Life Cycle Cost*			
Per ha	82,547	145,140	129,499
Per ac	33,377	58,685	52,361

* For a medium size site (5.41 ha).

TABLE 19a. UNIT OPERATION 14. CHEMICAL INJECTION

Use: Chemical injection destroys or insolubilizes a pollutant.

Configuration: This process entails injecting reactive chemicals into the landfill. The process is highly waste specific.

Conjunctive Uses: None listed.

Assume:
1. Landfill received cyanide salts in drums.
2. Use sodium hypochlorite to insolubilize cyanide.
3. Initial probing shows drums destroyed, material dissolved.
4. Only 1/4 landfill affected.
5. Only temporarily effective.
6. Water supply available.
7. Concentration gradients well defined.

TABLE 19b. COSTS OF CHEMICAL INJECTION FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Exploratory Boring 16-13 m (d) (208 m)	2,870	4,860	4,260
Drill Rig Rental (53 days)	14,840	24,910	22,260
Chemicals, Sodium Hypochlorite (140,000 l)	17,200	23,700	21,000
Drilled Holes - Cased (2-1/2" pipe) 4 m Centers (841 injection wells - 13 m deep)	126,820	263,050	228,390
Surveying (2 days)	310	520	460
Capital Cost (subtotal)	162,650	317,040	276,370
Overhead Allowance (25 percent)	40,510	79,260	69,090
Contingency Allowance (30 percent)	48,610	95,110	82,910
Total Capital Cost	251,160	491,412	428,370
O&M Costs			
Monitoring			
Sample Collection 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis -Primary & Secondary Parameters - 12 background/yr - 12 downgradient/yr 24 samples/yr	7,900	7,900	7,900
Total Life Cycle Cost (over 10 years)	324,170	571,240	506,521
Average Life Cycle Cost*			
Per m^3	2.16	3.81	3.38
Per ft^3	0.0612	0.108	0.0957

* For 150,000 m^3 of landfill volume at a medium size site (5.41 ha).

TABLE 20a. UNIT OPERATION 15. EXCAVATION AND DISPOSAL AT SECURE LANDFILL

Use: The excavation and reburial of a landfill involves digging up the existing material, loading and transporting the waste to secure site, and reburying.

Configuration: None.

Conjunctive Uses: None listed.

Assume:

1. Removal of entire landfill, and transporting to a new landfill 20 miles away (32 km).
2. New site already has permit to receive wastes.
3. Operational monitoring wells in place at receiving landfill.
4. Hazardous waste surcharge of 50 percent for excavation and transportation includes increased costs due to:
    - a. Personnel safety equipment
    - b. Increased labor rest time
    - c. Equipment modification and decontamination
    - d. Increased insurance costs
    - e. Transportation permits.

TABLE 20b. COSTS OF EXCAVATION AND DISPOSAL AT SECURE LANDFILL FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Total Cost includes: (596,388 m^3, 357,832 tons). Excavation/grading (includes truck loading)	944,140	1,094,190	1,056,680
Transportation, 30-ton dump truck (64 km RT)	687,040	1,465,680	1,248,120
Hazardous Waste Surcharge for Excavation and Transportation (50 percent)	815,590	1,279,940	1,152,400
Tipping Fee	39,361,520	39,361,520	39,361,520
Capital Cost (subtotal)	41,808,290	43,201,330	42,818,720
Overhead Allowance (25 percent)	10,452,070	10,800,330	10,704,680
Contingency Allowance (40 percent)	16,723,320	17,280,530	17,127,490
Total Capital Cost	68,983,680	71,282,190	70,650,890
O&M Cost			
Monitoring (at new site)			
Sample Collection 12 days/yr (96 hr/yr labor)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
- Primary & Secondary Parameters			
- 12 background/yr			
- 12 downgradient/yr			
24 Samples/yr			
Total O&M Costs	8,660	9,470	9,270
No maintenance is necessary.			
Total Life Cycle Cost (over 10 years)	69,056,690	71,362,020	70,729,040
Average Life Cycle Cost*			
Per m^3	116	120	119
Per ft^3	3.28	3.39	3.36

* For a 596,390 m^3 total landfill volume at a medium size site (5.41 ha).

TABLE 21a. UNIT OPERATION 16. PONDING

Use: Ponding is a method for controlling surface water runoff at both municipal and industrial landfills.

Configuration: Drainage trenches are excavated and constructed along with the pond.

Conjunctive Uses: Contour grading and revegetation are commonly used.

Assume:
1. A 2"-24 hr rainfall event.
2. Evaporation and percolation are the methods by which water leaves the pond.
3. Adjacent land for pond is already available.

TABLE 21b. COSTS OF PONDING FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation and Grading, Soil (Pond & Drainage Area) (625 m^3)	570	660	640
Berm Construction (5,280 m^3)	1,850	3,170	2,750
Capital Cost (subtotal)	2,420	3,830	3,390
Overhead Allowance (25 percent)	600	960	850
Contingency Allowance (20 percent)	480	770	680
Total Capital Cost	3,500	5,560	4,920
O&M Costs			
Pond has 10-year life span; no maintenance required.			
Total Life Cycle Cost (over 10 years)	3,500	5,560	4,920
Average Life Cycle Cost*			
Per ha of site size	647	1,028	909
Per ac of site size	262	416	368

* For a medium size site (5.41 ha).

TABLE 22a. UNIT OPERATION 17. TRENCH CONSTRUCTION

Use: A trench is constructed around the landfill to control surface discharge escape of leachate.

Configuration: A trench is constructed to a depth of 2.0 m, using 2:1 slopes, around the perimeter of the landfill.

Conjunctive Uses: None noted.

Assume: 1. The trench is placed around the perimeter of the landfill.

TABLE 22b. COSTS OF TRENCH CONSTRUCTION FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation and Grading, Soil ($5,260\ m^3$)	4,740	5,530	5,320
Spread Excavated Material ($5,260\ m^3$)	3,360	4,000	3,840
Capital Cost (subtotal)	8,100	9,530	9,160
Overhead Allowance (25 percent)	2,030	2,380	2,290
Contingency Allowance (15 percent)	1,220	1,430	1,370
Total Capital Cost	11,350	13,340	12,820
O&M Costs			
Grubbing (clearing) (1 time per year) ($2,630\ m^2$)	320	660	570
Total O&M Costs	320	660	570
Total Life Cycle Cost (over 10 years)	14,050	18,900	17,630
Average Life Cycle Cost*			
Per m	15.11	20.32	18.96
Per ft	4.61	6.20	5.78

* For a 930 m trench at a medium size site (5.41 ha).

TABLE 23a. UNIT OPERATION 18. PERIMETER GRAVEL TRENCH VENTS

Use: Perimeter gravel trenches help to minimize migration and manage the escape of gases from landfills to the atmosphere.

Configuration: A trench is excavated around the perimeter of the landfill and backfilled with gravel material.

Conjunctive Uses: None listed.

Assume: 1. Gravel trench is placed around the perimeter of the landfill.

TABLE 23b. COSTS OF PERIMETER GRAVEL TRENCH VENTS FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Trench Excavation (7,300 m^3) (935 m (L) x 6 m (d) x 1.3 m (w))	9,710	11,050	10,720
Gravel Material (7,300 m^3)	51,880	79,430	70,050
Spread Excavated Material (7,300 m^3)	4,670	5,550	5,330
Capital Cost (subtotal)	66,260	96,030	86,100
Overhead Allowance (25 percent)	16,560	24,010	21,520
Contingency Allowance (15 percent)	9,940	14,400	12,910
Total Capital Cost	92,760	134,440	120,530
O&M Costs			
Grubbing (Surface of Trench) (1 time per year) (935 m^2)	110	240	200
Total O&M Costs	110	240	200
Total Life Cycle Cost (over 10 years)	93,690	136,460	122,220
Average Life Cycle Cost*			
Per m	100	146	131
Per ft	30.52	44.45	39.81

* For a 935 m trench at a medium size site (5.41 ha).

TABLE 24a. UNIT OPERATION 19. TREATMENT OF CONTAMINATED GROUND WATER

Use: Treatment facilities are used to treat contaminated ground water so it can be safely discharged into a receiving stream.

Configuration: The treatment system includes the following processes:

1. Influent piping from extraction wells.
2. Treatment plant (chemical, biological, and/or physical treatment).
3. Treated water discharge system.

Conjunctive Uses: Well point systems or deep well systems are used to collect the ground water.

Assume:

1. Ground water has a high concentration of a contaminant and must be treated before it can be discharged into a receiving stream.
2. The costs presented here are not considered fixed. The cost of treating ground water can vary considerably depending on what unit processes and flow rates are used to treat the water.
3. The landfill is close to treatment facilities.

TABLE 24b. COSTS OF TREATMENT OF CONTAMINATED GROUND WATER FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Treatment System (440,740 l/d) includes influent piping (6" - 300 m)	406,000	687,300	603,200
Capital Cost (subtotal)	406,000	687,300	603,200
Overhead Allowance (25 percent)	101,500	171,830	150,800
Contingency Allowance (40 percent)	162,400	274,920	241,280
Total Capital costs	669,900	1,134,050	995,280
O&M Costs			
Operating Cost (3 operators) (2,080 hr/yr) (6,240 hr/yr total)	39,300	81,740	71,100
Power Cost (electricity) (32,000 kWh/yr)	1,600	1,600	1,600
Chemical cost (16,922/d) x 260 d/yr	11,000	11,000	11,000
Total O&M Costs	51,900	94,340	83,700
Total Life Cycle Cost (over 10 years)	1,108,590	1,930,520	1,702,060
Average Life Cycle Cost*			
Per l/day	2.52	4.38	3.86
Per gal/day	9.52	16.58	14.62

* For treating 440,740 l of contaminated ground water/day at a medium size site (5.41 ha).

TABLE 25a. UNIT OPERATION 20. GAS MIGRATION CONTROL (Trench Vents - Passive)

Use: Trench vents are used primarily to attenuate lateral gas or vapor migration. This is a passive means of controlling gas migration.

Configuration: Trench vents are constructed by excavating a deep, narrow trench surrounding the waste site or spanning a section of perimeter. The trench is backfilled with gravel. There are five types of trench vents:

1. Open trench (see Perimeter Gravel Trenches).
2. Open trench with liner.
3. Closed trench with laterals and risers and liner (see below).
4. Induced draft (see Gas Migration Control, Active).
5. Air injection.

Conjunctive Uses: Well point system is used.

Assume:
1. Use of lateral risers and a synthetic liner.
2. Well point dewatering done for one month.
3. Laterals with risers: Laterals 0.3 m (12 in) PVC; risers 0.15 m (6 in) PVC pipe by 4.5 m long, placed every 15 m along the lateral.
4. Liner consists of hypalon (36 mil) bracketed with heavyweight geotextile fabric.

TABLE 25b. COSTS OF GAS MIGRATION CONTROL, PASSIVE, FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Trench Excavation (4,255 m^3) 935 m (L) x 3.5 m (d) x 1.3 m (w)[†]	5,660	6,440	6,250
Spread Excavated Material (2,850 m^3)[†]	1,820	2,160	2,080
Gravel (2,850 m^3)[†]	18,750	28,950	25,520
Pipe, PVC: 12" Lateral (935 m);	40,670	56,190	49,650
Riser Pipe, 6" (290 m)	8,380	14,820	13,170
Liner (5,700 m^2)	24,820	42,010	36,870
Backfill (1,405 m^3)[†]	2,470	2,960	2,840
Monitoring Program			
Monitoring Equipment	500	500	500
Monitoring Wells, Gas (32) (1/2" PVC, 3.6 m deep)	760	1,500	1,300
Capital Costs (subtotal)	103,830	155,530	138,180
Overhead Allowance (25 percent)	25,960	38,880	34,540
Contingency Allowance (20 percent)	20,770	31,110	27,640
Total Capital Costs	150,560	225,520	200,360
O&M Costs			
Monitoring 24 times/yr (4 hr/time) (96 hr/yr) (labor costs)	760	1,600	1,370
Total Life Cycle Cost (over 10 years)	156,970	239,010	211,910
Average Life Cycle Cost[*]			
Per m	168	256	227
Per ft	51.26	78.10	69.26

[*] For 935 m of trench length around a medium size site (5.41 ha).

[†] Also components in active gas migration control.

TABLE 26a. UNIT OPERATION 21. GAS MIGRATION CONTROL (Gas Collection System - Active)

Use: Gas collection systems are used when forced ventilation of trench vents is needed.

Configuration: They consist of pipe vents connected to a blower and directly discharging to the atmosphere or treatment device.

Conjunctive Uses: None listed.

Assume:
1. A collection system in which a blower is connected to pipe vents.
2. All manifold components are sized for 0.15 m (6 in) piping diameters.
3. Costs include installation.

TABLE 26b. COSTS OF GAS MIGRATION CONTROL, ACTIVE, FOR MEDIUM SIZE LANDFILL

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Trench[†]	28,700	40,510	36,690
Blower 1,250 cfm (2 hp)	1,110	1,870	1,640
PVC Pipe: Risers (290 m) 4 in;	6,080	11,160	9,770
Laterals (935 m) 8 in	26,720	40,670	36,000
PVC Pipe Tees 8 in (25)	2,370	3,920	3,440
Butterfly Valves 8 in (5)	1,060	1,800	1,580
Flow Meter 8 in (1)	650	1,360	1,180
PVC Pipe Elbows 8 in (25)	1,680	2,530	2,230
Moisture Traps (10)	3,360	5,700	4,990
Monitoring Program			
Monitoring Equipment	500	500	500
Monitoring Wells, Gas (32)	760	1,500	1,300
Capital Costs (subtotal)	72,990	111,520	99,320
Overhead Allowance (25 percent)	18,250	27,880	24,830
Contingency Allowance (30 percent)	14,600	22,300	19,860
Total Capital Costs	105,840	161,700	144,010
O&M Costs			
Monitoring 24 hr per time, 24 times per year (96 hr/yr) (labor costs)	760	1,600	1,370
Power Cost 1.5 kWh @ 2 hp = 12,900 kWh/yr (0.05/kWh) (8,600 hr/yr operation)	645	645	645
Operating Cost 40 hr/mo (480 hr/yr)	4,540	9,430	8,210
Total O&M Costs	5,945	11,675	10,225
Total Life Cycle Cost (over 10 years)	156,430	260,590	230,680

Table 26b (continued)

Capital Costs	Dollars		
	Lower U.S.	Upper U.S.	Newark, NJ
Average Life Cycle Cost*			
Per m	167	279	247
Per ft	50.95	85.12	75.36

* For 935 m of trench length around a medium size site (5.41 ha).

† Trench excavation, spreading excavated material, gravel, and backfill per previous unit operation of passive gas migration control.

TABLE 27a. UNIT OPERATION 22. POND CLOSURE AND CONTOUR GRADING OF SURFACE

Use: To enhance and control runoff from the disposal area and thereby reduce percolation (and consequently leachate production) and erosion.

Configuration: Pond berms and local borrow are utilized to fill emptied pond (sludge retained in pond bottom). Grading and compacting of this surface result in a profile of between 6 and 12 percent slope on crown, with side slopes of fill no steeper than 18 percent.

Surface water diversion is included in unit operations consisting of upgradient runoff berm and drainage channels to direct runoff around fill and downslope side.

Conjunctive Uses: Surface sealing, revegetation.

Assume: 1. Suitable soil from berms and adjacent borrow pit.

2. Final slope is 0.5 m above average grade.

TABLE 27b. COSTS OF POND CLOSURE AND CONTOUR GRADING FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation and Grading, Soil ($3,910\ m^3$)	3,520	4,100	3,950
Soil Compaction ($3,910\ m^3$)	4,920	6,610	6,140
Diversion Ditch, Construction ($140\ m^3$)	250	510	440
Surveying (2 days)	310	520	460
Capital Costs (subtotal)	9,000	11,740	10,990
Overhead Allowance (25 percent)	2,250	2,940	2,750
Contingency Allowance (15 percent)	1,350	1,760	1,650
Total Capital Costs	12,600	16,440	15,390
O&M Costs			
Assume twice annual ditch repair.			
Maintenance & Repair Cost - Diversion Ditch ($140\ m^3$)	500	1,020	880
Total O&M Costs	500	1,020	880
Total Life Cycle Cost (over 10 years)	16,820	25,040	22,810
Average Life Cycle Cost*			
Per ha	35,940	53,504	48,739
Per ac	14,500	21,586	19,664

* For a medium size impoundment (0.468 ha).

TABLE 28a. UNIT OPERATION 23. BITUMINOUS CONCRETE SURFACE SEALING OF CLOSED IMPOUNDMENT

Use: An impermeable cap placed on closed graded surface of pond (with sludges retained) eliminates infiltration of water and thus eliminates any leachate production. Especially useful under condition where residual sludges must be encapsulated and/or isolated from the environment.

Configuration: Either a cementaceous substance (lime, fly ash, or portland cement) is mixed with cover soils and allowed to set or an impermeable layer is used in conjunction with soil cover materials of the latter variety include clay, asphalt (bitumen), plastic membranes, and concrete. Used only on closed graded impoundment covering sludge residues or contaminated soil.

Conjunction Uses: Contour grading and revegetation.

Assume: 1. Seal complete for entire site.

TABLE 28b. COSTS OF BITUMINOUS CONCRETE SURFACE SEALING FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Surface Seat, Bituminous Concrete* (4,680 m^2) 3 in, 0.08 m thick	14,180	20,680	18,300
Capital Cost (subtotal)	14,180	20,680	18,300
Overhead Allowance (25 percent)	3,540	5,170	4,580
Contingency Allowance (35 percent)	4,960	7,240	6,400
Total Capital Costs	22,680	33,090	29,280
O&M Costs			
Assume 10-year life span.			
Total O&M Costs	0	0	0
Total Life Cycle Cost (over 10 years)	22,680	33,090	29,280
Average Life Cycle Cost†			
Per ha	48,462	70,705	62,564
Per ac	19,552	28,526	25,461

* See price list for alternative surface sealing materials/installation.

† For a medium size site (0.468 ha).

TABLE 29a. UNIT OPERATION 24. REVEGETATION

Use: Revegetation acts as an erosion retardant and also reduces infiltration of water by enhancing transpiration loss of soil moisture.

Configuration: Two configurations are possible - First: On contour graded closed (and perhaps capped) pond. Second: revegetation of berms or other surface water diversion structures to reduce erosion.

Conjunctive Uses: Contour grading and surface sealing.

Assume: 1. Use with closed contour graded pond.

2. Native grasses used for seed variety.

3. Soil will be mulched to add stability and moisture retention until vegetation takes hold.

TABLE 29b. COSTS FOR REVEGETATION FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Area Prep (4,680 m^2)	330	550	500
Hydroseeding (4,680 m^2)	430	600	510
Mulching (4,680 m^2)	120	180	160
Capital Costs (subtotal)	880	1,330	1,170
Overhead Allowance (25 percent)	220	330	290
Contingency Allowance (10 percent)	90	130	120
Total Capital Costs	1,190	1,790	1,580
O&M Costs			
Grass Mowing Cost (min $10 visit, 6 times/yr)	60	60	60
Refertilizing Cost (4,680 m^2)	20	30	30
Total O&M Costs	80	90	90
Total Life Cycle Cost (over 10 years)	1,860	2,550	2,340
Average Life Cycle Cost*			
Per ha	3,974	5,449	5,000
Per ac	1,603	2,198	2,017

* For medium size site (0.468 ha).

TABLE 30a. UNIT OPERATION 25. SLURRY TRENCH CUTOFF WALL

Use: Cutoff wall is used to lower ground water table below site.

Configuration: A bentonite slurry or bentonite soil-cement slurry is pumped into trench as excavation progresses. Trench is then backfilled with excavated material which has been mixed with the slurry. The effect of this construction practice is that the backfilled trench has a much lower coefficient of permeability than the surrounding soil and thus represents a barrier to ground water flow.

Conjunctive Uses: Contour grading, surface sealing, revegetation, extraction wells.

Assume:

1. Slurry consists of 1 part Wyoming Bentonite mixed with 12 parts water.
2. Contractor is licensed for installation of all parts of process which are patented.
3. Testing of wall ($2,000) SCS estimate.
4. Site is graded and surface is sealed.
5. Trench extends at former berm perimeter around 4 sides to 15 m in depth.
6. Geotechnical investigation.
7. Monthly monitoring of upgradient and downgradient wells.

TABLE 30b. COSTS FOR SLURRY TRENCH CUTOFF WALL FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Trench Excavation (4,165 m^3)	5,540	6,290	6,080
Bentonite, Delivered (165 tonnes)	11,000	29,200	27,400
Slurry Wall Installation (4,165 m^3)	134,110	226,990	199,090
Slurry Wall Testing	1,260	2,620	2,260
Capital Costs (subtotal)	161,410	284,600	251,780
Overhead Allowance (25 percent)	40,350	71,150	62,945
Contingency Allowance (30 percent)	48,420	85,380	75,534
Total Capital Costs	250,180	441,130	390,259
O&M Costs			
No maintenance required over 10-year life span.			
Total O&M Costs	0	0	0
Total Life Cycle Cost (over 10 years)	250,180	441,130	390,259
Average Life Cycle Cost*			
Per m^2	60.07	105.90	93.70
Per ft^2	5.58	9.84	8.70

* For 4,165 m^2 of wall face area at a medium size site (0.468 ha).

TABLE 31a. UNIT OPERATION 26. GROUT CURTAIN

Use: Grout curtain provides a barrier used to lower the ground water table below site.

Configuration: Cementaceous chemical solutions are injected into the subsurface through drilled injection borings under high pressure. Soil pores are filled and ground water movement impeded by tubelike structures of grouted soil-grouted injections are spaced so that they intersect to form an impermeable barrier.

Conjunctive Uses: Contour grading, surface sealing, revegetation, and extraction on wells.

Assume:

1. Chemical grout injected on 2 row gap pattern, injections spaced on 3 m centers, 15 m deep rows, soil porosity 25 percent, and phenolic resin grout $185/yd^3.
2. Patented process license held by contractor.
3. In-place testing, $2,000 SCS estimate.
4. Grout curtain surrounds site along former berm perimeter.
5. Geotechnical investigation.
6. Monthly monitoring of upgradient and downgradient wells.

TABLE 31b. COSTS OF GROUT CURTAIN FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Grout Curtain (4,465 m^3)	930,530	1,798,510	1,569,450
Capital Costs (subtotal)	940,030	1,818,010	1,586,400
Overhead Allowance (25 percent)	235,010	454,500	396,600
Contingency Allowance (30 percent)	282,010	545,400	475,920
Total Capital Cost	1,457,050	2,817,910	2,458,920
O&M Costs			
Monitoring Sampling 12 days/yr (96 hr/yr)	760	1,570	1,370
Analysis, 24 samples/yr (12 background/yr, 12 downgradient/yr)	7,900	7,900	7,900
Total O&M Costs	8,660	9,470	9,270
Total Life Cycle Cost (over 10 years)	1,530,060	2,897,740	2,537,070
Average Life Cycle Cost*			
Per m^2	373	706	618
Per ft^2	34.6	65.6	57.4

* For 4,104 m^2 of wall face area at a medium size site (0.468 ha).

TABLE 32a. UNIT OPERATION 27. SHEET PILING CUTOFF WALL

Use: As with grout curtain and slurry trench, purpose is to lower and/or divert ground water table below site.

Configuration: Interconnecting steel sheets are driven into the ground upgradient of the facility to lower ground water below site.

Conjunctive Uses: Contour grading, revegetation, and extraction systems (deep wells, well points).

Assume:

1. Sixty foot depth (15 m) possible.
2. Facility surrounded with piling.
3. Price of sheet piling is F.O.B. site.
4. Geotechnical Investigation.
5. Monthly monitoring of upgradient and downgradient wells.

TABLE 32b. COSTS OF SHEET PILING CUTOFF WALL FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Sheet Piling (442 tonnes)	200,450	295,400	261,090
Capital Costs (subtotal)	209,950	314,900	278,040
Overhead Allowance (25 percent)	52,490	78,720	69,510
Contingency Allowance (25 percent)	52,490	78,720	69,510
Total Capital Cost	314,930	472,340	417,060
O&M Costs			
Monitoring Sampling 12/days (96 hr/yr)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
Total O&M Costs	8,660	9,470	9,270
Total Life Cycle Cost (over 10 years)	387,940	552,170	495,210
Average Life Cycle Cost*			
Per m^2	95	135	121
Per ft^2	8.80	12.52	11.23

* For 4,100 m^2 of wall face area at a medium size site (0.468 ha).

TABLE 33a. UNIT OPERATION 28. GROUT BOTTOM SEAL

Use: Bottom of closed filled in pond is sealed with chemical cementing agent. Procedure involves injecting grout into the soil beneath the bottom of pond through numerous properly spaced, cased bore holes.

Configuration: Sludges buried in closed pond are isolated from ground water or are prevented from leaching contaminants to ground water, by properly spacing grout in soil underneath filled pond.

Conjunctive Uses: Contour grading, surface sealing, and revegetation.

Assume:
1. Sludges in pond bottom are either contacting or leaching contaminants to ground water.
2. Pond has been closed and filled in.
3. Chemical grout injected in gap pattern on 5 m centers.
4. Soil porosity 25 percent; phenolic resin grout.
5. Geotechnical investigation.
6. Seal 1 m thick.
7. Contour grading.
8. Assume 4 holes/day/drill rig.
9. Monthly monitoring of upgradient and downgradient wells.

TABLE 33b. COSTS OF GROUT BOTTOM SEAL FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Surveying (2 days)	300	520	460
Grout Injection Well System: (160 days - Drill Rig + 1,600 m - Drilled Holes Cased)	69,760	117,500	104,300
Grout Curtain (800 m^3)	166,720	322,280	281,240
Capital Cost (subtotal)	246,280	459,800	402,950
Overhead Allowance (25 percent)	61,570	114,950	100,740
Contingency Allowance (40 percent)	98,510	183,920	161,180
Total Capital Costs	406,360	758,670	664,870
O&M Costs			
Monitoring			
Sampling 12/days (96 hr/yr)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
Total O&M Costs	8,660	9,470	9,270
Total Life Cycle Cost (over 10 years)	479,370	838,500	743,020
Average Life Cycle Cost*			
Per ha	1,024,295	1,791,667	1,587,650
Per ac	413,250	723,000	640,534

* For a medium size site (0.468 ha).

TABLE 34a. UNIT OPERATION 29. TOE AND UNDERDRAINS

Use: Interceptor drain collects percolating leachate from facility and conveys contaminated water away from facility.

Configuration: Perforated asbestos and cement pipe is placed in gravel packed trench at a depth of 4.5 to 5 m with pipe in bottom. This intercepts leachate plume. A header pipe collector conveys collected leachate away from site.

Conjunctive Uses: Contour grading, surface sealing, revegetation, bottom sealing, grout curtain, slurry trench, and leachate treatment.

Assume:

1. Active or closed pond leaching high concentration of contaminants to top of ground water table.
2. Single interceptor trench parallel to pond downgradient from berm.
3. Leachate pumped to adjacent sewer.
4. Trenching costs include covering of installed drain pipe and gravel.
5. Sump installation costs include sump and discharge.

TABLE 34b. COSTS OF TOE AND UNDERDRAINS FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Trench Excavation (300 m^3) 5 m (d) x 1 m (w) x 60 m (L)	400	450	440
Cement Pipe (70 m)	570	880	770
Gravel (70 m^3)	500	760	710
Sump (1)	1,100	1,870	1,630
Pump, Submersible (1)	550	900	790
Capital Costs (subtotal)	12,620	24,360	21,290
Overhead Allowance (25 percent)	3,160	6,090	5,320
Contingency Allowance (25 percent)	3,160	6,090	5,320
Total Capital Costs	18,940	36,540	31,930
O&M Costs			
Monitoring Sampling 12 days (96 hr/yr)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
Electric Power - 1,800 kWh	100	100	100
Total O&M Costs	8,760	9,570	9,370
Total Life Cycle Cost (over 10 years)	92,860	117,290	110,990
Average Life Cycle Cost*			
Per m	1,548	1,955	1,850
Per ft	471	595	563

* For 60 m of trench length at a medium size site (0.468 ha).

TABLE 35a. UNIT OPERATION 30. WELL POINT SYSTEM

Use: A well point system is utilized to collect and remove leachate plume from ground water.

Configuration: A row of well points are driven into soil and extend just below bottom of leachate plume. A system of headers and pumps conveys leachate away from site.

Conjunctive Uses: Contour grading, revegetation, surface sealing, cutoff walls (grout, slurry, sheet piling), and leachate treatment.

Assume:
1. Bottom of leachate plume is within 5 m of surface.
2. Geotechnical investigation.
3. Discharge to adjacent sewer.

TABLE 35b. COSTS OF WELL POINT SYSTEM FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Drill Rig Rental (1 day)	280	470	420
Well Points (26 m)	1,040	1,760	1,540
Well Point Fittings (5)	40	70	60
Pump, Centrifugal (1)	1,600	1,600	1,600
Capital Costs (subtotal)	12,460	23,400	20,570
Overhead Allowance (25 percent)	3,120	5,850	5,140
Contingency Allowance (25 percent)	3,120	5,850	5,140
Total Capital Costs	18,700	35,100	30,850
O&M Costs			
Monitoring Sampling 12 days (96 hr/yr)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
Electricity (10,000 kWh)	500	500	500
Total O&M Costs	9,160	9,970	9,770
Total Life Cycle Cost (over 10 years)	96,280	119,510	113,580
Average Life Cycle Cost*			
Per m^2	321	398	379
Per ft^2	28	35	33

* For a 300 m^2 intercept face area at a medium size site (0.468 ha).

TABLE 36a. UNIT OPERATION 31. DEEP WELL SYSTEM

Use: Dewatering soils where greater depths than can be managed by well point systems are required.

Configuration: A system of extraction wells, each with its own pump is placed downgradient of the pond facility to extract contaminated ground water.

Conjunctive Uses: Pond closure practices (i.e., grading, sealing, surface water diversion), and leachate treatment.

Assume:

1. Pond leachate plume extends below 5 m in depth.
2. Geotechnical investigation.
3. Dewatering to 12 m.
4. Wells 14 m deep.
5. One day per well for installation.
6. 150 m discharge pipe to water treatment.
7. Assume all necessary fittings for each well cost equivalent to (1) 90° elbow and (1) tee connection.
8. 1 m deep trench for discharge pipe.

TABLE 36b. COSTS OF DEEP WELL SYSTEM FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Drill Rig Rental (5 days)	1,400	2,350	2,100
Drilled Holes - Cased (70 m), 6 in	1,090	1,850	1,620
Pumps, Submersible (5)	2,750	4,500	3,950
Well Fittings - 5 Wells	800	1,320	1,150
Header and Discharge Pipe (175 m)	4,320	6,690	5,880
Discharge Trench (175 m^3)	490	730	660
Capital Costs (subtotal)	20,350	36,940	32,310
Overhead Allowance (25 percent)	5,090	9,240	8,080
Contingency Allowance (30 percent)	6,100	11,080	9,690
Total Capital Costs	31,540	57,260	50,080
O&M Costs			
Monitoring Sampling 12 days (96 hr/yr)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
Electricity - 9,000 kWh	450	450	450
Total O&M Costs	9,110	9,920	9,720
Total Life Cycle Cost (Over 10 years)	108,670	141,220	132,350
Average Life Cycle Cost*			
Per m^2	114.39	148.65	139.32
Per ft^2	10.65	13.85	12.98

* For a 950 m^2 intercept face area at a medium size site (0.468 ha).

TABLE 37a. UNIT OPERATION 32. WELL INJECTION SYSTEM

Use: Injection wells are used to either dilute leachate plume or to cause a local ground water gradient reversal to stop the movement of leachate plume. Can also be used to inject chemicals to treat leachate in the ground.

Configuration: Leachate barrier is provided by inducing a local ground water gradient reversal through water injection wells, combined with extraction wells.

Conjunctive Uses: Contour grading, surface sealing, revegetation.

Assume:
1. Same system as Unit Operation 31.
2. Only difference is water is injected.
3. No submersible pumps.
4. One centrifugal pump for 5 wells.
5. Water available at no cost.

TABLE 37b. COSTS OF WELL INJECTION SYSTEMS FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Geotechnical Investigation	9,500	19,500	16,950
Drill Rig Rental (5 days)	1,400	2,350	2,100
Drilled Holes - Cased (5 holes, 6 in, 70 m)	1,090	1,850	1,620
Pump, Centrifugal (1)	1,600	1,600	1,600
Well Fittings (5 wells)	800	1,320	1,150
Header and Discharge Pipe (175 m)	4,320	6,690	5,880
Discharge Trench (175 m^3)	490	730	660
Capital Costs (subtotal)	19,200	34,040	29,960
Overhead Allowance (25 percent)	4,800	8,510	7,490
Contingency Allowance (30 percent)	5,760	10,210	8,990
Total Capital Costs	29,760	52,760	46,440
O&M Costs			
Monitoring Sampling 12 days (96 hr/yr)	760	1,570	1,370
Analysis (24 samples/yr)	7,900	7,900	7,900
Electricity (2,000 kWh)	100	100	100
Total O&M Costs	8,760	9,570	9,370
Total Life Cycle Cost (over 10 years)	103,680	133,510	125,500
Average Life Cycle Cost*			
Per m^2	109	141	132
Per ft^2	10.16	13.09	12.30

* For a 950 m^2 intercept face area at a medium size site (0.468 ha).

TABLE 38a. UNIT OPERATION 33. LEACHATE TREATMENT

Use: Leachate and contaminated ground water removed by extraction. (Deep well system needs treatment prior to discharge to receiving body of water.)

Configuration: System includes treatment plant and discharge system to nearby body of receiving water.

Conjunctive Uses: None listed.

Assume:

1. Ponds leak 8.14 litres of contaminated water per square meter per day.
2. Extraction wells draw twice the volume of contaminated water as leaks from pond.
3. Land costs for treatment plant not included.
4. Leachate easily treated with/by chemical treatment processes (conventional).

TABLE 38b. COSTS OF LEACHATE TREATMENT FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Treatment Plant (51,780 l/day)	36,250	61,360	53,850
Capital Cost (subtotal)	36,250	61,360	53,850
Overhead Allowance (25 percent)	9,060	15,340	13,460
Contingency Allowance (40 percent)	14,500	24,540	21,540
Total Capital Costs	59,810	101,240	88,850
O&M Costs			
Operator (1) (2,080 hr/yr)	16,470	34,010	29,680
Chemicals (51,780 influent L/d)	1,290	1,290	1,290
Electricity (50,000 kWh)	2,500	2,500	2,500
Total O&M Costs	20,260	37,800	33,470
Total Life Cycle Cost (over 10 years)	232,420	421,720	372,830
Average Life Cycle Cost*			
Per L/d	4.49	8.14	7.20
Per gal/d	16.99	30.83	27.25

* For treating 51,780 l of contaminated water/day at a medium size site (0.468 ha).

TABLE 39a. UNIT OPERATION 34. BERM RECONSTRUCTION

Use: Eroded and leaking pond berm is reconstructed to properly contain wastes.

Configuration: A 3 m wide section of berms outer slope is rebuilt through excavating and regrading of berm.

Conjunctive Uses: None listed.

Assume:

1. Berms will be reconstructed to original size.
2. Equivalent of 1.5 m of berm outer slope has eroded away.
3. Additional 1.5 m of outer slope removed and reconstructed in place.
4. Suitable borrow soil available adjacent to site at no cost.

TABLE 39b. COSTS OF BERM RECONSTRUCTION FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation and Grading, Soil ($410\ m^3$)	360	420	400
Soil Compaction ($410\ m^3$)	510	690	640
Capital Costs (subtotal)	870	1,110	1,040
Overhead Allowance (25 percent)	220	280	260
Contingency Allowance (15 percent)	130	170	160
Total Capital Costs	1,220	1,560	1,460
O&M Costs			
Grubbing (once per year $380\ m^2$)	50	100	80
Total O&M Costs	50	100	80
Total Life Cycle Cost (over 10 years)	1,640	2,400	2,130
Average Life Cycle Cost*			
Per m^3	4.00	5.85	5.20
Per yd^3	3.06	4.48	3.97

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* For $410\ m^3$ of berm reconstruction at a medium size site (0.468 ha).

TABLE 40a. UNIT OPERATION 35. EXCAVATION AND DISPOSAL AT SECURE LANDFILL

Use: Excavation of hazardous sludges and contaminated soil from site unsuitable for final disposal and removal to secure landfill to prevent ground water contamination.

Configuration: Berms, sludges, and 1 m of contaminated soil are excavated from site and hauled to and disposed of at secure landfill.

Conjunctive Uses: None listed.

Assume:
1. Sludges hazardous and pose potential threat of leachate entering ground water.
2. Soil is not contaminated below a depth of 1 m.
3. Ponds are dry and sludge is dry.
4. No extreme recautionary measures necessary during excavation and transportation.
5. Transported in transfer trailers 15 m^3 capacity.
6. Thirty-two km one way between pond and secure landfill.
7. Costs of backfilling excavated ponds not included.
8. Soil and sludge weight 2.08 ton/m^3.
9. Hazardous waste surcharge of 50 percent for excavation and transportation includes increased costs due to:
    a. Personnel safety equipment
    b. Increased labor rest time
    c. Equipment modification and decontamination
    d. Increased insurance costs
    e. Transportation permits.

TABLE 40b. COSTS OF EXCAVATION AND DISPOSAL AT SECURE LANDFILL FOR MEDIUM SIZE IMPOUNDMENT

	Dollars		
Capital Costs	Lower U.S.	Upper U.S.	Newark, NJ
Excavation (3,340 m^3) Using Front-End Loader to Load Trucks	2,500	2,870	2,770
Transportation, 30-Ton Dump Truck (6,950 tons, 64 km RT) + Hazardous Waste Surcharge for Excavation and Transportation	7,920	15,670	13,510
Tipping Fee (6,950 ton)	764,500	764,500	764,500
Capital Cost (subtotal)	788,260	811,510	805,020
Overhead Allowance (25 percent)	197,070	202,880	201,260
Contingency Allowance (40 percent)	315,300	324,600	322,010
Total Capital Costs	1,300,630	1,338,990	1,328,290
O&M Costs			
Assume no O&M costs			
Total Life Cycle Cost (over 10 years)	1,300,630	1,338,990	1,328,290
Average Life Cycle Cost*			
Per m^3	260	268	266
Per gal	0.985	1.014	1.006

* For a 5,000 m^3 impoundment volume at a medium size site (0.468 ha).

SECTION 8

EXAMPLE REMEDIAL ACTION SCENARIOS

INTRODUCTION

This section is intended to show how this report may be used to help develop an estimated cost for a remedial action scenario. The purposes of undertaking corrective action at a disposal site are to correct existing environmental problems, to prevent their occurrence in the future, and to bring the site into compliance with current regulations. It is important to emphasize that seldom, if ever, will the implementation of a single corrective action unit operation be effective in correcting all of the environmental problems that may exist at a given site. Rather, it will usually be necessary to design and implement an integrated corrective action program or strategy consisting of several unit operations.

The selection and design of a corrective action plan should be carefully evaluated in terms of its regulatory requirements, technical considerations, operational ramifications, and short- and long-term economic feasibility. Except in the most straightforward cases, a corrective action plan should be established by a multidisciplinary team of professionals, including environmental, civil, and soils engineers, geologists, hydrogeologists, chemical engineers, and other specialists as warranted. The following is a partial list of important considerations in any corrective action plan:

- Implementation of a corrective action plan can represent a substantial investment.
- Site-specific factors will have a profound influence on the practicality and effectiveness of the various corrective action techniques.
- Following implementation of the plan, the site must usually be maintained and monitored over the long term.

In the following subsections, a hypothetical remedial action scenario is presented, involving a combination of unit operations. The estimated cost for the hypothetical remedial action is then calculated using the cost data presented earlier in this report.

HYPOTHETICAL PROBLEM

Description of Site Conditions

An abandoned hazardous waste site has been investigated and is found to be contaminating surface and ground water. It is decided that the site must be isolated by (a) preventing surface runoff from entering the stored hazardous waste, (b) preventing ground water migration through the site, and (c) implementing a monitoring program to confirm the effectiveness of the steps taken. The unit operations required are as follows:

- Contour grading and surface water division (see Unit Operation 1 in Section 7).
- Surface sealing (see Unit Operation 2 in Section 7).
- Bentonite slurry trench cutoff wall. Monitoring is included in unit operation (see Unit Operation 4 in Section 7).

Description of Site Size

For example purposes, it is assumed that the hypothetical site has the following dimensions:

- Surface area = 4 hectares (10 acres).
- Site is square, 200 meters (218 yards) each side.
- Average depth of bentonite slurry trench cutoff wall must be 10 meters (11 yards) to impervious material.
- Hydrological investigation indicates that bentonite slurry trench cutoff wall must extend around three sides of site to cut off ground water migration through the site.

Surface Cost Estimation

The procedure for estimating the cost of this hypothetical remedial action scenario is as follows:

1. Refer to the pertinent tables in Section 7, and list the components of the unit operations selected. This step is shown in Table 41, first column.

TABLE 41. SAMPLE CALCULATION OF REMEDIAL ACTION COSTS FOR HYPOTHETICAL LANDFILL

Column No.	2	3	4	5	6
Source of Information for this Column	Appendix	Section 8	Appendix	Col. 3 x 4	Col. 5
Unit Operation and Components	Unit of Measurement	Calculate No. of Units This Scenario	U.S. High Component Per Unit - $	Cost Component Total - $	Unit Operation Total - $
Unit Operation 1. Contour grading and surface water diversion, from Table					
a) Excavation, grading, and recontouring of site - labor plus equipment	m^3	0.5 m x 40,000 m^2 = 20,000 m^3	1.83	36,600	
b) Excavation and grading soil, labor plus equipment	m^3	0.3 m x 40,000 m^2 = 12,000 m^3	1.05	12,600	
c) Diversion ditch	m^3	4 m x 2 m x 200 m = 1,600 m^3	3.63	5,800	
d) Capital cost (subtotal)				55,000	
e) Overhead allowance, 25%				13,750	
f) Contingency allowance, 15%				8,250	
g) Total capital cost					77,000
h) Maintenance and repair cost, diversion ditch (2 times per year)	m^3	1,600 m^3 x 2 = 3,200	3.60	11,520	
i) Total O&M costs (Present worth in 1980 dollars)					97,000
j) Total ten-year life cycle cost					174,000

TABLE 41 (continued)

Column No.	2	3	4	5	6
Source of Information for this Column	Appendix	Section 8	Appendix	Col. 3 x 4	Col. 5
Unit Operation and Components	Unit of Measurement	Calculate No. of Units This Scenario	U.S. High Component Per Unit - $	Cost Component Total - $	Unit Operation Total - $
Unit Operation 2. Bentonite concrete surface sealing					
a) Excavation, grading, and recontouring of site - included in unit operation No. 1, thus not duplicated here	m^3				
b) Excavation and grading soil - included in unit operation No. 1, thus not duplicated here	m^3				
c) Surface seal, bituminous concrete cap (0.08 m, 3") installation & materials	m^2	40,000 m^2	4.55	182,000	
d) Capital cost (subtotal)				182,000	
e) Overhead allowance, 25%				45,500	
f) Contingency allowance, 35%				63,700	
g) Total capital cost					291,200
h) Maintenance and operation cost - none					
i) Total 10-year life cycle cost					291,200

TABLE 41 (continued)

Column No.	2	3	4	5	6
Source of Information for this Column	Appendix	Section 8	Appendix	Col. 3 x 4	Col. 5
Unit Operation and Components	Unit of Measurement	Calculate No. of Units This Scenario	U.S. High Component Per Unit - $	Cost Component Total - $	Unit Operation Total - $
Unit Operation 4. Bentonite slurry - trench cutoff wall					
a) Geotechnical investigation	Lump	1	6,520	6,520	
b) Slurry trench excavation and installation of bentonite slurry	m^3	220 m x 3 x 10 m x 1 = 6,600 m^3	54.5	359,700	
c) Bentonite, delivered	Tonnes	6,600 m^3 x 0.039 tonnes/m^3 = 257 tonnes	177	45,500	
d) Capital cost (subtotal)				411,700	
e) Overhead allowance, 25%				102,900	
f) Contingency allowance, 30%				123,500	
g) Total capital costs					638,100
h) Maintenance and operation, sample collection	Hour	96 hrs./yr.	16.60	1,594	
i) Maintenance and operation, sample analysis	Sample	24 samples/yr.	330	7,920	
j) Total of O&M costs (Present worth in 1980 dollars)					80,200
k) Total 10-year life cycle cost					718,300

2. Refer to the price list in the Appendix, and determine what units will be required to measure the cost of each component (e.g., hectares, square meters, etc.). This step is shown in Table 41, second column.

3. Calculate the number of units (e.g., hectares, square meters, etc.) of each cost component required for the site. This step is shown in Table 41, third column, for the hypothetical site used in this example.

4. Refer to the price list in the Appendix, and list the unit cost for each cost component required (e.g., $/hectare, $/square meter, etc.). A decision will have to be made on whether to use U.S. high, U.S. low, or New Jersey costs. For this example scenario, U.S. high costs were used, and are shown in Table 41, fourth column.

5. The final cost calculation requires multiplication of the number of units (Step 3 above) by the unit cost (Step 4 above), as appropriate, and summation of the cost components to arrive at a total cost. For this example, see Table 41, fifth and sixth columns.

For the hypothetical remedial action scenario used here as an example, the estimated costs were calculated as follows:

Total capital cost	$1,006,300
Total O&M cost, during 10 years	$177,200
Total 10-year life cycle cost	$1,183,500

SECTION 9

SCALE AND REGIONAL COST VARIATIONS

In addition to other site-specific considerations, unit operation cost estimates may vary substantially in response to scale economies and regional price differences. To demonstrate the extent to which these factors can affect unit operation cost estimates, lower U.S., upper U.S., and Newark, New Jersey, average life cycle costs for each of the five scales of site size were estimated for the following unit operations:

- No. 2, Landfill Bituminous Concrete Surface Sealing.
- No. 4, Landfill Slurry Trench Cutoff Wall.
- No. 15, Landfill Excavation and Disposal.
- No. 26, Impoundment Grout Curtain.
- No. 30, Impoundment Well Point System.

These life cycle averages were plotted and graphically interpolated to show the effects of scale and regional cost variations for these unit operations. Graphical interpolation by visually fitting curves to the points was used in preference to statistical curvefit techniques. The resulting curves appear in Figures 4 through 8.

In Figure 4, landfill bituminous concrete surface sealing shows negligible scale economies when the life cycle averages are expressed in terms of site area. This is because site area is the primary factor affecting costs of initial capital investment. Regional cost differentials, however, are large for all components, and thus result in widely spaced cost curves. Regional cost variations were especially prominent for the installed cost of the surface seal component, bituminous concrete.

In Figure 5, the landfill bentonite slurry trench cutoff wall shows some scale economies. Again, these gradual slopes result because the unit of measurement, wall face area, is expected to be highly correlated with total life cycle costs; regional differentials (i.e., relative distances between curves) are large because nearly all components are subject to regional price variations. Only the cost of monitoring sample analysis was assumed to be invariant with geographic setting.

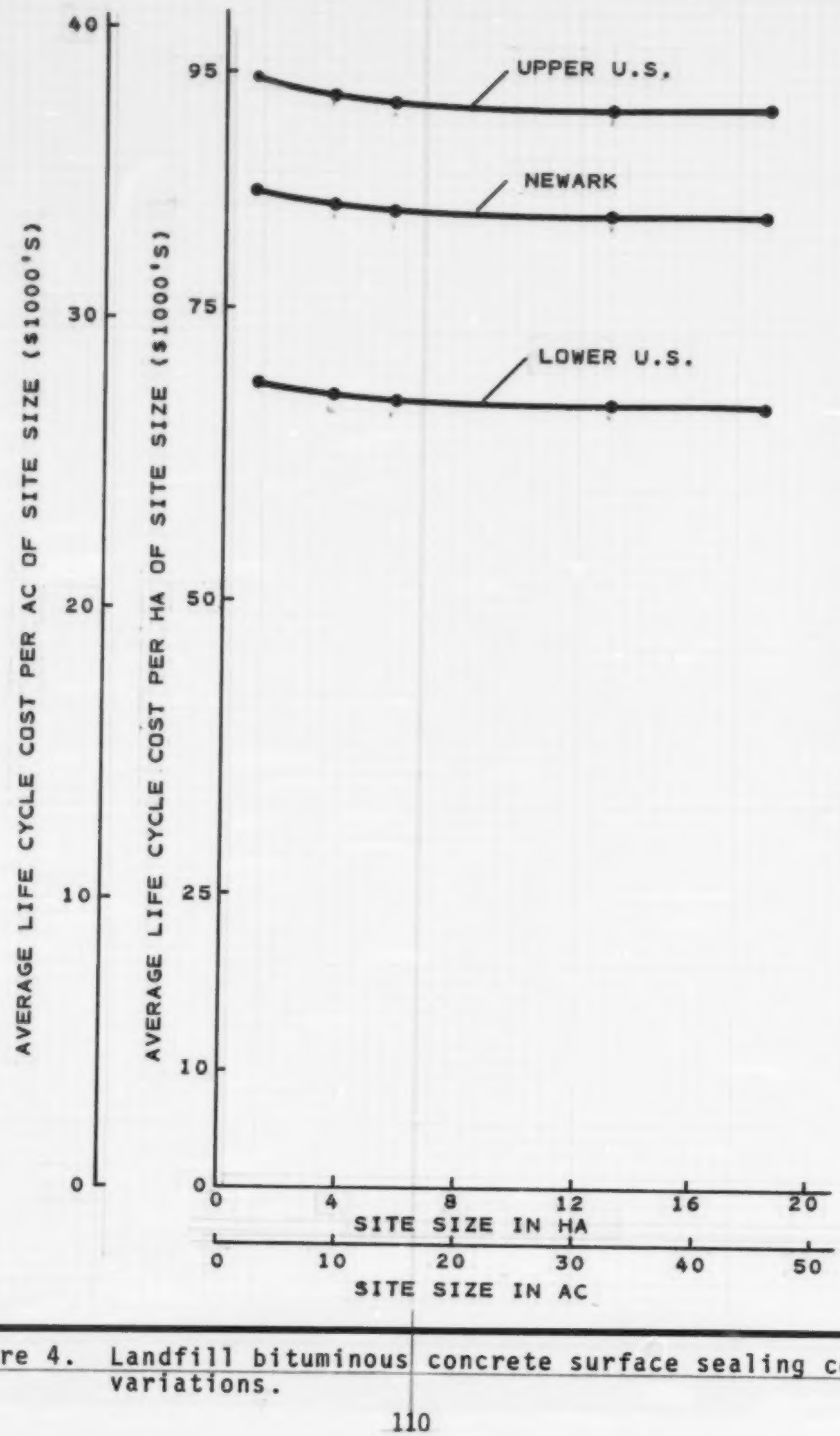

Figure 4. Landfill bituminous concrete surface sealing cost variations.

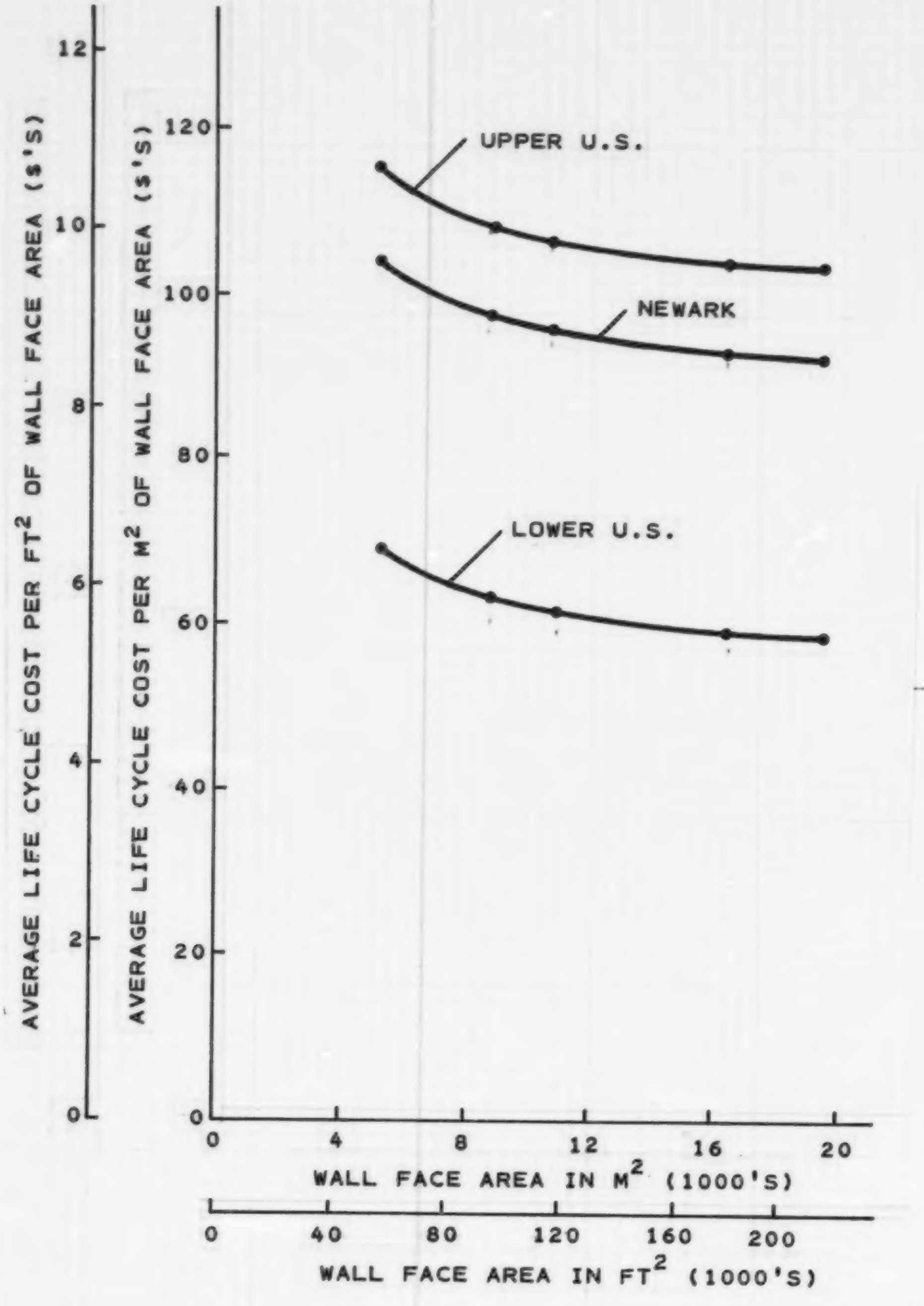

Figure 5. Landfill bentonite slurry trench cutoff wall cost variations.

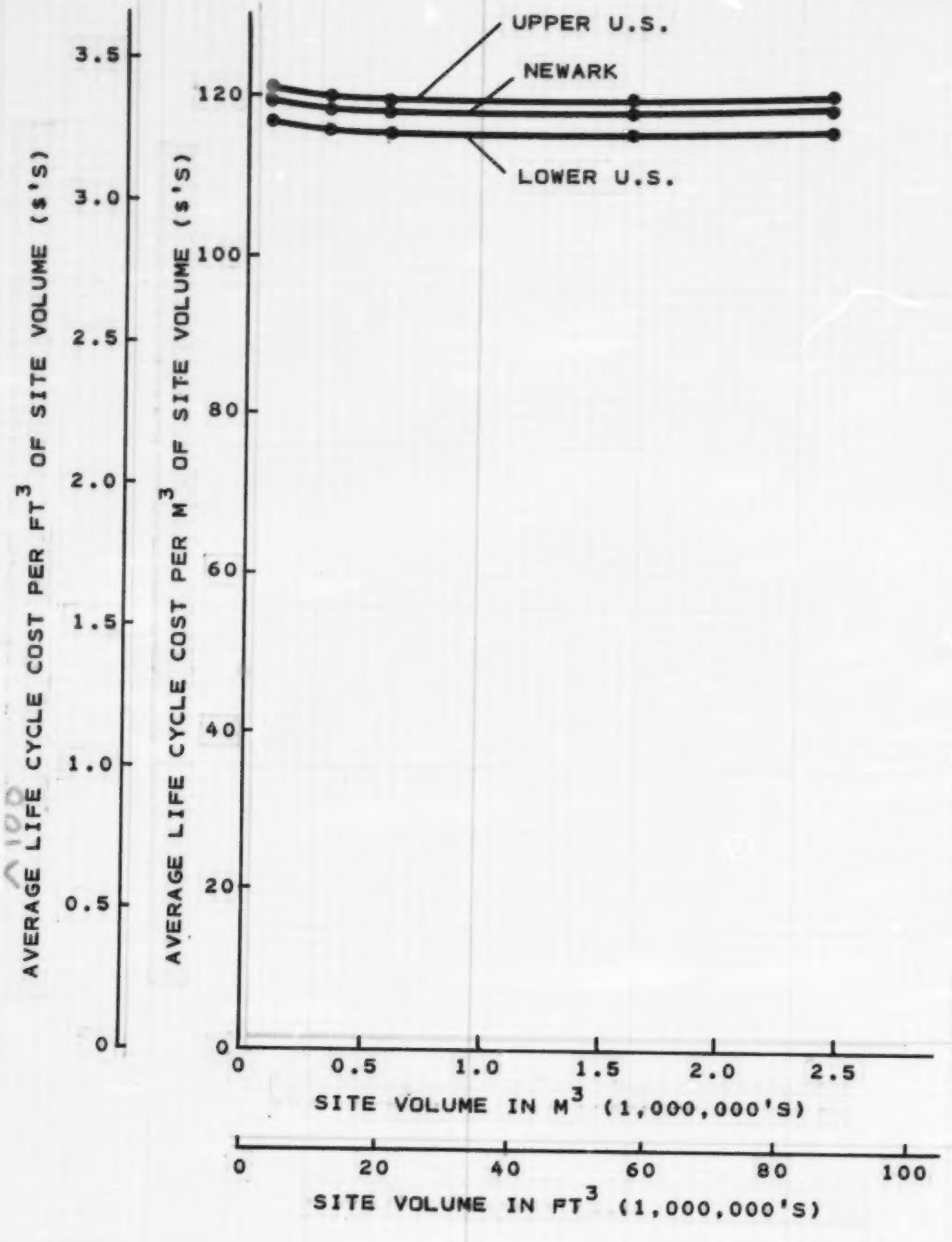

Figure 6. Landfill excavation and reburial cost variations.

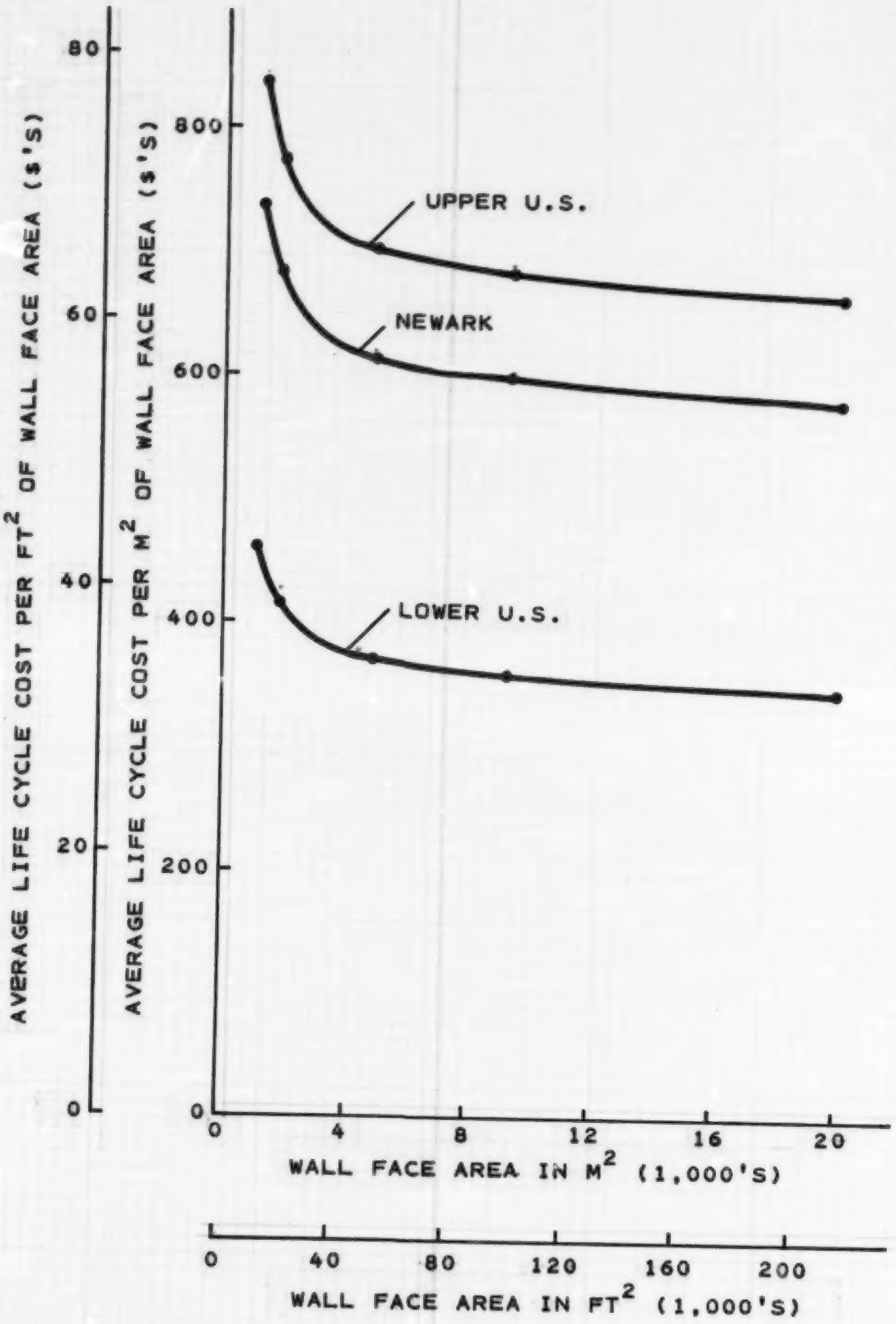

Figure 7. Impoundment grout curtain cost variations.

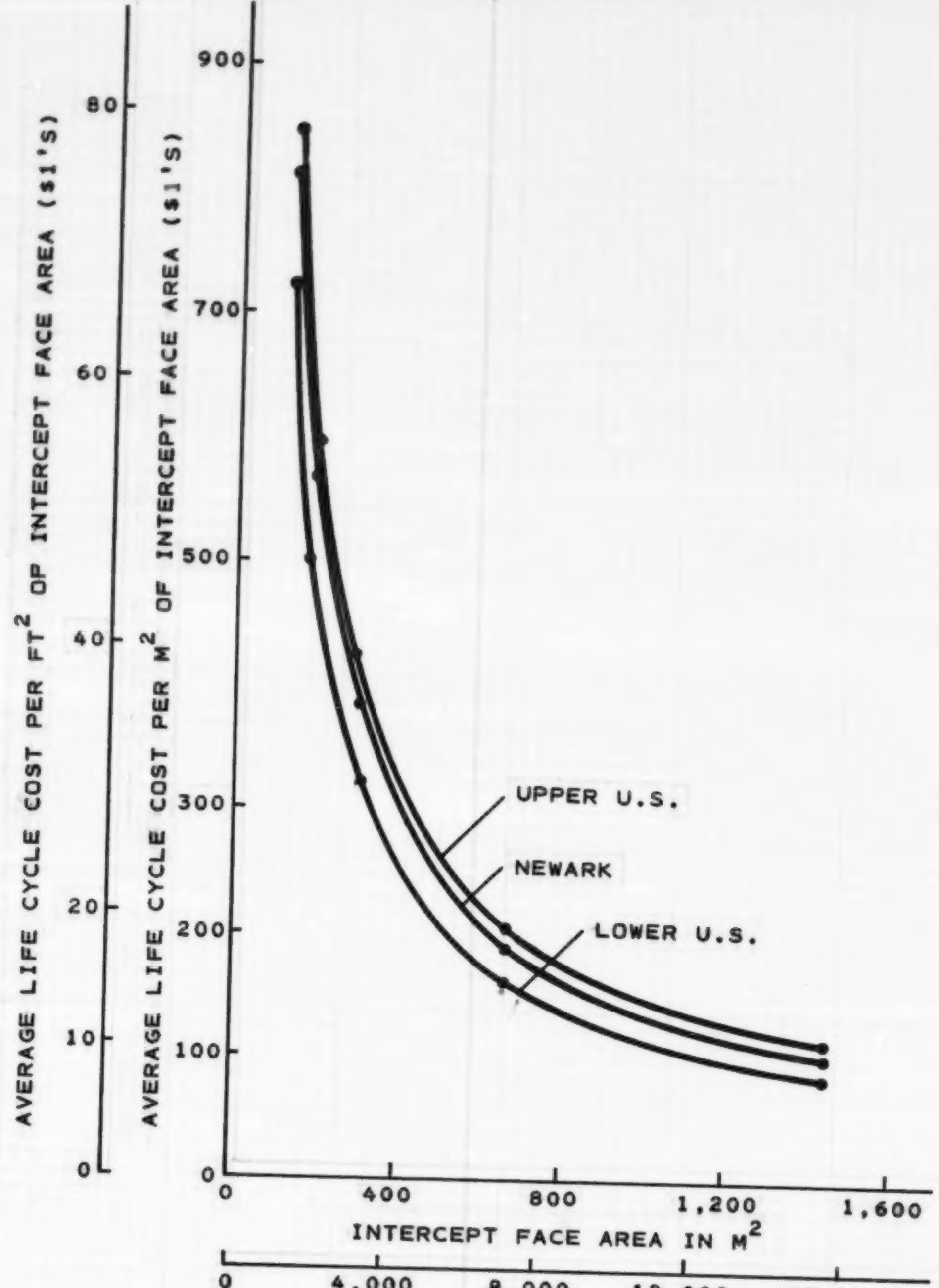

Figure 8. Impoundment well point system cost variations.

In Figure 6, landfill excavation and reburial has negligible scale economies when the average life cycle costs are expressed in terms of site volume. There is also only minor regional variation because an invariant tipping fee was used. Further research is needed to refine the tipping fee to reflect regional price differences.

In Figure 7, impoundment grout curtain shows moderate scale economies and substantial regional cost differentials due to price variations in its largest component, the grout material itself. This is another example of the influence that a major component can have on scale economies and regional cost differences.

Figure 8 shows another example of the pervasive influence which a single component can exert. In this case, there are large economies of scale and negligible regional cost variation due to the overpowering influence of costs for analyzing monitoring samples. Because such costs were not assumed to change when the intercept face area increased, substantial scale economies appeared. Because this major component was assumed to be invariant from one part of the country to another, the regional variation in average life cycle cost was suppressed.

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APPENDIX A

TABLE A-1. CAPITAL AND O&M COMPONENTS WHICH CONTRIBUTE TO UNIT OPERATIONS

	COMPONENTS UNIT OPERATIONS	Apply stabilized waste	Area preparation	Backfilling	Bentonite, delivered	Berm construction	Blower	Butterfly valves	Cement pipe	Chemicals	Deep wells	Dewatering system	Discharge pipe	Discharge trench	Diversion ditch, construction	Drilled holes - cased	Drill rig (rental)	Excavation	Excavation, drainage trench	Excavation/grading, soil	Excavation/grading/recontouring	Exploratory boring	Flow meters	Geotechnical investigation (LF)	Geotechnical investigation (SI)	Gravel	Grout curtain	Header pipe	Header/discharge pipe	Hydroseeding	Liner	Material testing	Moisture traps	Monitoring equipment	Monitoring wells, gas	Mulching	Pipe, PVC, elbows and tees	Pipe, PVC, laterals	Pipe, PVC, risers	Pump, centrifugal	Pump, submersible	Recharge trench	Sand	Sheet piling	Slurry trench excavation	Slurry wall, installation	Slurry wall, testing	Soil compaction	Spread excavated materials	Sump	Surface seal	Surveying	Tipping fees	Transportation	Treatment plant	Treatment system	Trench excavation	Well fittings	Well points	Well point fittings	CONJUNCTIVE USE BY UNIT OP. NUMBER	Chemicals	Electricity	Grass mowing	Grubbing	Maintenance/repair, diversion ditch	Monitoring	Monitoring (analysis)	Monitoring (sample collection)	Operating cost	Operator	Refertilization	Water
LANDFILL	1. Contour grading														●					●	●																																										3, 20, 21					●							
	2. Surface sealing																			●	●																														●										1, 3, 13												
	3. Revegetation		●																			●									●						●																											1, 20, 21			●								●	
	4. Bentonite wall					●																				●																					●																		1, 2, 3							●	●				
	5. Grout curtain															●							●			●																																						1, 2, 3							●	●				
	6. Sheet piling wall																																												●																		1, 2, 3												
	7. Grout bottom sealing																						●					●					●																				●										1, 3							●	●				
	8. Drains				●					●							●										●															●																●				1, 3		●					●	●				
	9. Well point system													●										●				●												●		●	●						●											●	●	1, 3		●					●	●				
	10. Deep well system											●	●	●												●		●																●	●						●													1, 3		●					●	●				
	11. Injection											●													●																●																								1, 3		●					●	●				●
	12. Subgrade irrigation									●		●								●							●															●							●																	●					●	●				
	13. Chemical fixation		●																		●	●																																										1, 3							●	●				
	14. Chemical injection										●						●	●					●																														●														●			●	●				
	15. Excavation/burial																					●																																		●	●												●			●	●				
	16. Ponding						●														●																																											1, 3												
	17. Trench construction																				●																													●																											
	18. Perimeter trench vents																										●																							●									●																
	19. Ground water treatment																																																										●					9, 10	●	●							●			
	20. Gas control-passive				●																						●				●			●	●			●	●										●									●				9						●						
	21. Gas control-active				●			●	●														●			●						●	●	●		●	●	●										●									●						●				●			●			
IMPOUNDMENTS	22. Pond closure/grading															●					●																												●				●										23, 24					●							
	23. Surface sealing																																																			●										22, 24												
	24. Revegetation		●																											●						●																											22, 23			●								●	
	25. Slurry trench					●																					●																					●	●											●				22-24, 30, 31												
	26. Grout curtain																									●		●																																				22-24, 30, 31							●	●				
	27. Sheet piling wall																									●																			●																		22, 24, 30, 31							●	●				
	28. Grout bottom seal																●								●		●																									●										22, 23, 24							●	●				
	29. Toe and underdrains									●																●	●														●								●						●				22-26, 28, 33		●					●	●				
	30. Well point system																	●								●														●																			●	●	22-27, 33		●					●	●				
	31. Deep well system														●		●	●								●				●												●																	●			22-24, 33		●					●	●				
	32. Well injection														●		●	●								●				●											●																		●			22, 23, 24		●					●	●				
	33. Leachate treatment																																																							●								●	●								●		
	34. Berm reconstruction																				●																											●																		●								
	35. Excavation/disposal																		●																																		●	●																				
		CAPITAL COSTS																																																											O & M COSTS											

TABLE A-2. AVERAGE U.S. LOW AND HIGH COSTS OF UNIT OPERATIONS FOR MEDIUM-SIZED SITES - METRIC UNITS

Unit Operations	Typical Metric Units	Average U.S. Low Cost Per Unit			Average U.S. High Cost Per Unit		
		Initial Capital $	First Year O&M $	Life Cycle Cost $	Initial Capital $	First Year O&M $	Life Cycle Cost $
1. Contour grading and surface water diversion	Site area, ha	15,300	114	16,300	17,900	240	19,900
2. **Bituminous concrete surface sealing**	Site area, ha	67,300	0	67,300	92,700	0	92,700
3. Revegetation	Site area, ha	3,450	105	14,300	16,500	185	18,100
4. Bentonite slurry trench cutoff wall	Wall face area, m.^{2}	54.5	0.802	61.2	96.1	0.877	103
5. Grout curtain	Wall face area, m.^{2}	600	0.80	937	1,209	0.88	1880
6. Sheet piling cutoff wall	Wall face area, m.^{2}	73	0	73	108	0	108
7. **Grout bottom sealing**	Site area, ha	5,282,000	1,600	5,296,000	10,209,000	1,750	10,224,000
8. Drains	Pipe length, m.	72.7	33.7	357	106	36.8	416
9. Well point system	Intercept face area, m.^{2}	62.5	5.23	107	105	5.64	153
10. Deep well system	Intercept face area, m.^{2}	11.6	2.1	28.6	18.3	2.22	37.2
11. Injection	Intercept face area, m.^{2}	77	199	1,760	90	201	1,785
12. **Leachate recirculation by subgrade irrigation**	Site area, ha	5,270	1,700	19,700	8,360	1,850	24,000
13. Chemical fixation	Site area, ha	69,100	1,600	82,500	130,000	1,750	145,000
14. Chemical injection	Landfill volume, m.^{3}	1.67	.0577	2.16	3.28	.0631	3.81
15. Excavation and reburial	Landfill volume, m.^{3}	116	0.015	116	120	0.016	120

TABLE A-2 (continued)

Unit Operations	Typical Metric Units	Average U.S. Low Cost Per Unit: Initial Capital $	Average U.S. Low Cost Per Unit: First Year O&M $	Average U.S. Low Cost Per Unit: Life Cycle Cost $	Average U.S. High Cost Per Unit: Initial Capital $	Average U.S. High Cost Per Unit: First Year O&M $	Average U.S. High Cost Per Unit: Life Cycle Cost $
16. Ponding	Site area, ha	647	0	647	1,028	0	1,028
17. Trench construction	Trench length, m.	12.2	0.344	15.11	14.34	0.710	20.32
18. **Perimeter gravel trench vents**	Trench length, m.	99.2	0.118	100	144	0.257	146
19. Treatment of contaminated ground water	Contaminated water, 1./d	1.52	0.118	2.52	2.57	0.214	4.38
20. Gas migration control - passive	Site perimeter, m.	161	0.813	168	241	1.71	256
21. Gas migration control - active	Site perimeter, m.	113	6.36	167	173	12.4	279
22. Pond closure and contour grading of surface	Site area, ha.	26,900	1,070	35,900	35,100	2,180	53,500
23. **Bituminous concrete surface sealing of closed impoundment**	Site area, ha.	48,500	0	48,500	70,700	0	70,700
24. Revegetation	Site area, ha.	2,540	171	3,970	3,820	192	5,450
25. Slurry trench cutoff wall	Wall face area, m.^{2}	60.1	0	60.1	105	0	105
26. Grout curtain	Wall face area, m.^{2}	326	1.94	343	631	2.12	649
27. Sheet piling cutoff wall	Wall face area, m.^{2}	76.8	2.11	94.6	115	2.31	135
28. Grout bottom seal	Site area, ha	868,000	18,500	1,024,000	1,621,000	20,200	1,792,000
29. Toe and underdrains	Pipe length, m.	316	146	1,550	609	160	1,960
30. Well point system	Intercept face area, m.^{2}	62.3	32.5	321	117	33.2	398
31. Deep well system	Intercept face area, m^2	33.2	9.59	114.4	60.3	10.4	149
32. Well injection system	Intercept face area, m.^{2}	31.3	9.22	109	55.5	10.1	141
33. Leachate treatment	Contaminated water, L./d	1.16	0.391	4.49	1.96	0.730	8.14
34. Berm reconstruction	Replaced berm, m.^{3}	2.98	0.122	4.00	3.80	0.244	5.85
35. Excavation and disposal at secure landfill	Impoundment volume, m.^{3}	260	0	260	268	0	268

TABLE A-3. AVERAGE U.S. LOW AND HIGH COSTS OF UNIT OPERATIONS FOR MEDIUM-SIZED SITES - ENGLISH UNITS

		Average U.S. Low Cost Per Unit			Average U.S. High Cost Per Unit		
Unit Operations	Typical English Units	Initial Capital $	First Year O&M $	Life Cycle Cost $	Initial Capital $	First Year O&M $	Life Cycle Cost $
1. Contour grading and surface water diversion	Site area, ac.	6,210	46.3	6,600	7,240	97.2	8,060
2. Bituminous concrete surface sealing	Site area, ac.	27,200	0	27,200	37,500	0	37,500
3. Revegetation	Site area, ac.	5,440	42.6	5,800	6,680	74.7	7,310
4. Bentonite slurry trench cutoff wall	Wall face area, ft.^{2}	5.05	0.075	5.69	8.93	0.081	9.62
5. Grout curtain	Wall face area, ft.^{2}	55.8	0.075	87	112	0.081	175
6. Sheet piling cutoff wall	Wall face area, ft.^{2}	6.81	0	6.80	10.1	0	10.1
7. Grout bottom sealing	Site area, ac.	2,136,000	10.3	2,141,000	4,128,000	708	4,134,000
8. Drains	Pipe length, ft.	22.1	9.26	109	32.3	11.2	127
9. Well point system	Intercept face area, ft.^{2}	5.81	0.486	9.97	9.72	0.524	14.2
10. Deep well system	Intercept face area, ft.^{2}	1.04	0.190	2.66	1.70	0.206	3.46
11. Injection	Intercept face area, ft.^{2}	7.18	18.0	164	8.38	18.7	166
12. Leachate recirculation by subgrade irrigation	Site area, ac.	2,130	688	7,960	3,380	748	9,720
13. Chemical fixation	Site area, ac.	27,900	647	33,400	52,700	708	58,700
14. Chemical injection	Landfill volume, ft.^{3}	.0474	.00164	.0612	.0928	.00179	.108
15. Excavation and reburial	Landfill volume, ft.^{3}	3.28	.0004	3.28	3.39	.0004	3.39

TABLE A-3 (continued)

Unit Operations	Typical English Units	Average U.S. Low Cost Per Unit Initial Capital $	 First Year O&M $	 Life Cycle Cost $	Average U.S. High Cost Per Unit Initial Capital $	 First Year O&M $	 Life Cycle Cost $
16. Ponding	Site area, ac.	262	0	262	416	0	416
17. Trench construction	Trench length, ft.	3.72	0.105	4.61	4.37	0.216	6.20
18. Perimeter gravel trench vents	Trench length, ft.	30.2	0.036	30.5	43.8	0.078	44.5
19. Treatment of contaminated ground water	Contaminated water, gal./d	5.75	0.446	9.52	9.74	0.810	16.6
20. Gas migration control - passive	Site perimeter, ft.	141	0.710	51.26	211	1.90	78.10
21. Gas migration control - active	Site perimeter, ft.	98.9	5.56	50.95	151	10.9	85.12
22. Pond closure and contour grading of surface	Site area, ac.	10,900	431	14,500	14,200	879	21,600
23. Bituminous concrete surface sealing of closed impoundments	Site area, ac.	19,600	0	19,600	28,500	0	28,500
24. Revegetation	Site area, ac.	1,030	69.0	1,600	1,540	77.6	2,200
25. Slurry trench cutoff wall	Wall face area, ft.^{2}	5.58	0	5.58	10.07	0	10.07
26. Grout curtain	Wall face area, ft.^{2}	30.4	0.180	31.9	58.7	0.197	80.4
27. Sheet piling cutoff wall	Wall face area, ft.^{2}	7.14	0.196	8.80	10.7	0.215	12.5
28. Grout bottom seal	Site area, ac.	350,000	7,470	413,250	654,000	8,160	723,000
29. Toe and underdrains	Pipe length, ft.	96.1	44.4	471	185	48.6	595
30. Well point system	Intercept face area, ft.^{2}	5.50	2.69	28.3	10.3	2.93	35.2
31. Deep well system	Intercept face area, ft.^{2}	3.09	0.893	10.65	5.61	0.972	13.9
32. Well injection system	Intercept face area, ft.^{2}	2.92	0.859	10.16	5.17	0.938	13.1
33. Leachate treatment	Contaminated water, gal./d	4.37	1.48	17	7.40	2.76	30.8
34. Berm reconstruction	Replaced berm, yd.^{3}	2.28	0.093	3.06	2.91	0.187	4.48
35. Excavation and disposal at secure landfill	Impoundment volume, gal.	.985	0	.986	1.014	0	1.014

TABLE A-4. LANDFILL CAPITAL COST COMPONENTS - METRIC UNITS

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Apply stabilized waste	Installation	Hauling and spreading, 10 miles (16 km.), round trip	\$/m.^{3}	Means 1980	8.76	5.52	11.6	10.0
Area preparation	Labor	Rake and cleanup, average	\$/ha.	Dodge 1980	741	469	963	839
Area preparation	Equipment	Rake and cleanup, average	\$/ha.	Dodge 1980	222	222	222	222
Backfill	Labor	Dozer and sheepsfoot roller	\$/m.^{3}	Means 1980	0.51	0.32	0.64	0.58
Backfill	Equipment	Dozer and sheepsfoot roller	\$/m.^{3}	Means 1980	1.44	1.44	1.44	1.44
Bentonite, delivered	Materials/shipping	Shipment of bentonite by rail	\$/tonne	Burlington Northern 1980		66.4	177	166.
Berm construction	Materials/installation	Use scraper	\$/m.^{3}	Dodge 1980	0.50	0.35	0.60	0.52
Blower	Materials/installation	Blower, air	\$/each	Britton 1980	1,150	800	1,360	1,200
Butterfly valves, 6"	Materials/installation	PVC valve	\$/each	Godfrey 1980	192	135	230	200
Butterfly valves, 8"	Materials/installation	PVC valve	\$/each	Godfrey 1980	304	213	360	317
Cement pipe, 4" perforated	Labor	Asbestos, Class 4000 underdrain	\$/m.	Means 1980	3.00	1.90	3.18	2.82
Cement pipe, 4" perforated	Materials	Asbestos, Class 4000 underdrain	\$/m.	Means 1980	5.08	3.91	5.38	4.77
Cement pipe, 6" perforated	Labor	Asbestos, Class 4000 underdrain	\$/m.	Means 1980	3.10	1.95	4.06	3.53
Cement pipe, 6" perforated	Materials	Asbestos, Class 4000 underdrain	\$/m.	Means 1980	8.00	6.16	8.48	7.52
Cement pipe, 6"	Labor	Cement pipe, non-perforated	\$/m.	Means 1980	3.54	2.23	4.63	4.04
Cement pipe, 6"	Materials	Cement pipe, non-perforated	\$/m.	Means 1980	6.23	4.80	6.60	5.85
Chemicals	Materials	Treatment chemical, sodium hypochlorite (NaClO)	\$/l.	Purex 1980	0.16	0.12	0.17	0.15
Deep wells, 6"	Materials/labor	Drilled and cased	\$/m.	Means 1960	20.9	14.6	25.1	21.8
Dewatering system	Materials/labor	For cost breakdown, see "Discharge pipe", "submersible pump", "Deep wells"						
Discharge pipe, 4"	Labor	PVC plastic, Schedule 40	\$/m.	Means 1980	22.0	13.9	28.8	25.1
Discharge pipe, 4"	Materials	PVC plastic, Schedule 40	\$/m.	Means 1980	9.15	7.05	9.70	8.60

TABLE A-4 (continued)

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Discharge pipe, 8"	Labor	PVC plastic, Schedule 40	\$/m.	Means 1980	34.1	21.5	44.7	38.9
Discharge pipe, 8"	Materials	PVC plastic, Schedule 40	\$/m.	Means 1980	27.4	21.1	29.0	25.8
Diversion ditch, construction	Installation	Construction and maintenance/repair	\$/m.^{3}	Means 1980	2.78	1.75	3.63	3.13
Drilled holes, 2.5"	Materials/installation	Drilled and cased with pipe	\$/m.	Means 1980	18.3	11.6	24.1	20.9
Drilled holes, 6"	Materials/installation	Drilled and cased with pipe	\$/m.	Means 1980	22.3	15.6	26.4	23.2
Drill rig	Rental (Equip./labor)	Crew and light duty rig, and grading	\$/day	Means 1980	400	280	470	420
Excavation, drainage trench	Labor	Use backhoe loader	\$/m.^{3}	Means 1980	2.65	1.70	3.50	3.00
Excavation, drainage trench	Materials	Use backhoe loader	\$/m.^{3}	Means 1980	1.60	1.20	1.70	1.50
Excavation/grading, soil	Labor	Excavation/grading, soil, common borrow, 1000 ft (305 m.) haul	\$/m.^{3}	Dodge 1980	0.22	0.14	0.29	0.25
Excavation/grading, soil	Equipment	Excavation/grading, soil, common borrow, 1000 ft (305 m.) haul	\$/m.^{3}	Dodge 1980	0.76	0.76	0.76	0.76
Excavation, grading, and recontouring of site	Labor	300 ft (90 m.) haul, dozer and truck	\$/m.^{3}	Means 1980	0.37	0.23	0.48	0.42
Excavation, grading, and recontouring of site	Equipment	300 ft (90 m.) haul, dozer and truck	\$/m.^{3}	Means 1980	1.35	1.35	1.35	1.35
Exploratory boring	Materials/installation	Test strata in or below landfill, and to apply chemical injection, 4 in. (0.03 m.) diameter holes	\$/m.	Means 1980	19.7	13.8	23.2	20.5
Flow meters, 6"	Materials/installation	Measures rate of flow of landfill gas to blower	\$/each	Godfrey 1980	880	550	1,150	1,003
Flow meters, 8"	Materials/installation	Measures rate of flow of landfill gas to blower	\$/each	Godfrey 1980	1,040	650	1,360	1,180
Geotechnical investigation	Labor/materials	Includes exploratory holes, surveying, mobilization, drilling addition, pump test, and report	\$/site	SCS 1980	5,500	3,850	6,520	5,720
Gravel	Labor	One dozer operator, one truck driver	\$/m.^{3}	Means 1980	2.48	1.56	3.25	2.58
Gravel	Materials	3/4" screened gravel	\$/m.^{3}	Means 1980	7.20	5.54	7.63	7.50
Grout curtain	Labor	Two grid - pherolic resin (also for grout bottom seal)	\$/m.^{3}	Means 1980	262	165	343	298
Grout curtain	Materials	Two grid - pherolic resin (also for grout bottom seal)	\$/m.^{3}	Means 1980	56.2	43.3	59.6	52.8

TABLE A-4 (continued)

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Header pipe, 8"	Materials	PVC Schedule 40	\$/m.	Means 1980	27.4	21.1	29.0	25.8
Header pipe, 8"	Installation	PVC Schedule 40	\$/m.	Means 1980	34.1	21.5	44.7	38.9
Hydroseeding	Labor	Includes seed and soil supplements	\$/ha.	Dodge 1980	171	108	224	195
Hydroseeding	Materials	Includes seed and soil supplements	\$/ha.	Dodge 1980	877	675	929	824
Hydroseeding	Equipment	Includes seed and soil supplements	\$/ha.	Dodge 1980	124	124	124	124
Liner	Labor/materials	30 mil., bracketed with heavyweight geotextile fabric, Hypalon	$\$/m.^2$	Dupont 1980	6.22	4.35	7.37	6.47
Materials testing	Materials/installation	For costing, see "Exploratory Boring"						
Moisture traps	Materials/installation	Removes water from gas control system	\$/each	H&A Cons. 1980	480	335	570	500
Monitoring equipment	Equipment	Gas detection instrumentation to monitor gas control systems (MSA Model 53 Gascope)	\$/each	SCS 1980	500	500	500	500
Monitoring wells, gas	Materials	0.5" (1.3 cm.), 12 ft (3.6 m.) deep, for landfill gas monitoring	\$/m.	Means 1980	1.34	1.03	1.42	1.26
Monitoring wells, gas	Installation	0.5" (1.3 cm.), 12 ft (3.6 m.) deep, for landfill gas monitoring	\$/m.	Means 1980	8.82	5.55	11.5	10.0
Mulching	Labor	Hay mulching	\$/ha.	Dodge 1980	85.2	53.7	111	97.1
Mulching	Materials	Hay mulching	\$/ha.	Dodge 1980	210	162	223	197
Mulching	Equipment	Hay mulching	\$/ha.	Dodge 1980	57.3	57.3	57.3	57.3
Pipe, PVC (elbows), 6"	Materials	90° fitting	\$/each	Means 1980	27.0	20.8	28.6	25.4
Pipe, PVC (elbows), 6"	Installation	90° fitting	\$/each	Means 1980	28.0	17.6	36.7	31.9
Pipe, PVC (elbows), 8"	Materials	90° fitting	\$/each	Means 1980	52.0	40.0	55.1	48.9
Pipe, PVC (elbows), 8"	Installation	90° fitting	\$/each	Means 1980	39.0	24.6	51.1	44.5
Pipe, PVC (Tees), 6"	Materials	T-fittings for gas wells	\$/each	Means 1980	37.0	28.5	39.2	34.8
Pipe, PVC (Tees), 6"	Installation	T-fittings for gas wells	\$/each	Means 1980	46.0	29.0	60.3	52.4
Pipe, PVC (Tees), 8"	Materials	T-fittings for gas wells	\$/each	Means 1980	75.0	57.8	79.5	70.5
Pipe, PVC (Tees), 8"	Installation	T-fittings for gas wells	\$/each	Means 1980	59.0	37.2	77.3	67.3
Pipe, PVC, laterals, 8"	Materials	For gas extraction wells, Schedule 40 **(includes \$4.92/m for perforations)**	\$/m.	Means 1980	**29.20**	**22.5**	**30.9**	**27.5**

TABLE A-4 (continued)

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Pipe, PVC, laterals, 8"	Installation	For gas extraction wells, Schedule 40	\$/m.	Means 1980	9.65	6.08	12.6	11.0
Pipe, PVC, laterals, 12"	Materials	For gas extraction wells, Schedule 40 (includes \$4.92/m for perforations)	\$/m.	Means 1980	41.0	31.6	43.7	38.6
Pipe, PVC, laterals, 12"	Installation	For gas extraction wells, Schedule 40	\$/m.	Means 1980	15.4	11.9	16.4	14.5
Pipe, PVC, risers, 4"	Materials	For gas extraction wells, Schedule 40	\$/m.	Means 1980	9.15	7.05	9.70	8.60
Pipe, PVC, risers, 4"	Installation	For gas extraction wells, Schedule 40	\$/m.	Means 1980	22.0	13.9	28.8	25.1
Pipe, PVC, risers 6"	Materials	For gas extraction wells, Schedule 40	\$/m.	Means 1980	16.4	12.7	17.4	15.4
Pipe, PVC, risers 6"	Installation	For gas extraction wells, Schedule 40	\$/m.	Means 1980	25.7	16.2	33.7	30.0
Pump, centrifugal	Equipment/installation	3/4 HP pump	\$/each	Means 1980	1600	1600	1600	1600
Pump, submersible	Labor	1 HP - 4", submersible	\$/each	Means 1980	344	220	450	390
Pump, submersible	Materials	1 HP - 4" submersible	\$/each	Means 1980	424	330	450	400
Recharge trench	Materials/installation	Excavation of trench	$\$/m.^3$	Means 1980	1.60	1.12	1.90	1.66
Sand	Materials/installation	For well point casing backfill	\$/bag	Means 1980	5.80	4.06	6.87	6.03
Sheet piling	Materials	Steel sheet, PMA-22 (22 lbs/ft^2)	\$/tonne	Means 1980	507	390	537	477
Sheet piling	Installation	Install steel sheet, PMA-22 (22 lbs/ft^2)	\$/tonne	Means 1980	100	63	131	114
Slurry trench excavation	Materials/installation	Includes installation of bentonite slurry	$\$/m.^3$	Means 1980	46.0	32.2	54.5	47.8
Spread excavated material	Labor	One equipment operator, five laborers	$\$/m.^3$	Means 1980	0.21	0.13	0.25	0.22
Spread excavated material	Equipment	Spread by dozer, no compaction	$\$/m.^3$	Means 1980	0.51	0.51	0.51	0.51
Surface seal, bituminous concrete	Installation	3" (0.08 m.) thick cap	$\$/m.^2$	Means 1980	1.05	0.66	1.37	1.20
Surface seal, bituminous concrete	Materials	3" (0.08 m.) thick cap	$\$/m.^2$	Means 1980	3.00	2.31	3.18	2.82
Surface seal, clay cap	Materials/installation	6" (15-cm.) clay cap, includes 18" (46-cm.) soil cover	$\$/m.^2$	Martin 1978	4.82	3.50	6.41	5.49
Surface seal, clay cap	Materials/installation	18" (46-cm.) clay cap, includes 18" (46-cm.) soil cover	$\$/m.^2$	Martin 1978	6.18	4.51	8.22	7.05
Surface seal, fly ash cap	Materials/installation	12" (30-cm.) fly ash, includes 18" (46-cm.) soil cover	$\$/m.^2$	Martin 1978	4.65	3.40	6.18	5.30

TABLE A-4 (continued)

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Surface seal, fly ash cap	Materials/installation	24" (60-cm.) fly ash cap, includes 18" (46-cm.) soil cover	$/m.^{2}	Martin 1978	6.27	4.49	8.36	7.15
Surface seal, lime-stabilized cap	Materials/installation	5" (13-cm.) lime-stabilized cap, includes 18" (46-cm.) soil cover	$/m.^{2}	Martin 1978	6.05	5.24	8.04	6.90
Surface seal, PVC membrane cap	Materials/installation	30-mil PVC membrane cap, includes 18" (46-cm.) soil cover	$/m.^{2}	Martin 1978	10.8	9.7	14.4	12.3
Surface seal, soil-cement cap	Materials/installation	5" (13-cm.) soil-cement cap, includes 18" (46-cm.) soil cover	$/m.^{2}	Martin 1978	6.05	5.24	8.04	6.90
Surveying	Labor	Labor cost/day, establish surface topographic profile	$/day	SCS 1980	220	150	260	230
Tipping fees	Unit costs	Dumping and grading wastes at new site	$/tonne	SCS 1979	110	110	110	110
Transportation	Labor/equipment	30-ton dump truck/driver, based on one-way hauling distance, return trip included	$/tonne-km	SCS 1981	0.096	0.060	0.128	0.109
Transportation	Labor/equipment	15-ton dump truck/driver, based on one-way hauling distance, return trip included	$/tonne-km	SCS 1981	0.110	0.069	0.145	0.125
Treatment system	Unit costs	Typical costs - interpolated @ 0.12 MGD (440,000 l./d)	$/each	Dodge 1980	580K	406K	687K	603K
Trench excavation	Labor	One equipment operator/one laborer	$/m.^{3}	Means 1980	0.22	0.17	0.35	0.31
Trench excavation	Equipment	Tractor or hydraulic backhoe to excavate trench, sloped 1/2 to 1	$/m.^{3}	Means 1980	1.16	1.16	1.16	1.16
Well points, 2.5" (6.4 cm.) dia.	Materials/installation	PVC, 25 feet (7.6 m.)	$/m.	Davis 1980	59.3	41.5	70.3	61.7
Wellpoint fittings	Materials/installation	Fittings and accessories	$/well	Davis 1980	12.0	8.40	14.2	12.5

TABLE A-5. LANDFILL O&M COST COMPONENTS - METRIC UNITS

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Chemicals	Materials	Wastewater/leachate treatment plant chemicals	\$/l./day (influent)	SCS 1980	0.025	0.025	0.025	0.025
Electricity	Power costs	For water treatment plant, extraction, injection, and gas control well/pumps	\$/kwh	SCS 1980	0.05	0.05	0.05	0.05
Grubbing	Labor/equipment	Assume annual grubbing (clearing) of brush	$\$/m.^2$	Dodge 1980	0.19	0.12	0.25	0.22
Maintenance/repair, diversion ditch	Installation	Assume diversion ditch needs rebuilding 2 times a year after major storms	$\$/m.^3$	Means 1980	2.75	1.73	3.60	3.14
Monitoring	Labor	For gas monitoring at active and passive gas control installations	\$/hr.	SCS 1980	12.5	7.88	16.6	14.3
Monitoring (analysis)	Laboratory costs	For ground water/leachate monitoring from monitoring wells	\$/sample	SCS 1980	330	330	330	330
Monitoring (sampling)	Labor	For ground water/leachate monitoring from monitoring wells	\$/hr.	SCS 1980	12.5	7.88	16.6	14.3
Grass mowing	Labor/materials	Use 58" power ride mower, one operator	\$/ha	Dodge 1980	93.9	66.7	111	98.9
Operating cost	Labor	For water treatment plant operating personnel	\$/hr.	SCS 1980	10	6.30	13.10	11.39
Operating cost	Labor	For gas collection system operating personnel	\$/hr.	SCS 1980	15	9.45	19.95	17.10
Refertilization	Labor/materials	Assume refertilization once per year	\$/ha.	Dodge 1980	341	247	395	346
Water	Materials	Industrial process water	\$/kl	SCS 1980	0.92	0.92	0.92	0.92

TABLE A-6. LANDFILL CAPITAL COST COMPONENTS - ENGLISH UNITS

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Apply stabilized waste	Installation	Hauling and spreading, 10 miles (16 km.), round trip	$\$/yd.^3$	6.66	4.20	8.72	7.60
Area preparation	Labor	Rake and cleanup, average	$/acre	300	190	390	340
Area preparation	Equipment	Rake and cleanup, average	$/acre	90	90	90	90
Backfill	Labor	Dozer and sheepsfoot roller	$\$/yd.^3$	0.39	0.24	0.49	0.44
Backfill	Equipment	Dozer and sheepsfoot roller	$\$/yd.^3$	1.10	1.10	1.10	1.10
Bentonite, delivered	Materials/shipping	Shipment of bentonite by rail	$/ton		60.4	161.	159.
Berm construction	Materials/installation	Use scraper	$\$/yd.^3$	0.38	0.27	0.46	0.40
Blower	Materials/installation	Blower, air	$/each	1,150	800	1,360	1,200
Butterfly valves, 6"	Materials/installation	PVC valve	$/each	192	135	230	200
Butterfly valves, 8"	Materials/installation	PVC valve	$/each	304	213	360	317
Cement pipe, 4" perforated	Labor	Asbestos, Class 4000 underdrain	$/yd.	2.73	1.73	2.89	2.57
Cement pipe, 4" perforated	Materials	Asbestos, Class 4000 underdrain	$/yd.	4.62	3.56	4.90	4.34
Cement pipe, 6" perforated	Labor	Asbestos, Class 4000 underdrain	$/yd.	2.92	1.77	3.69	3.21
Cement pipe, 6" perforated	Materials	Asbestos, Class 4000 underdrain	$/yd.	7.28	5.61	7.72	6.84
Cement pipe, 6" perforated	Labor	Cement pipe, non-perforated	$/yd.	3.22	2.03	4.21	3.68
Cement pipe, 6" perforated	Materials	Cement pipe, non-perforated	$/yd.	5.67	4.37	6.01	5.32
Chemicals	Materials	Treatment chemical, sodium hypochlorite (NaClO)	$/gal.	0.61	0.45	0.64	0.57
Deep wells, 6"	Materials/labor	Drilled and cased	$/ft.	6.19	3.91	8.10	7.10
Dewatering system	Materials/labor	For cost breakdown, see "Discharge pipe", "Submersible pump", "Deep wells"					
Discharge pipe, 4"	Labor	PVC plastic, Schedule 40	$/yd.	20.0	12.6	26.2	22.8
Discharge pipe, 4"	Materials	PVC plastic, Schedule 40	$/yd.	8.33	5.42	8.83	7.86

TABLE A-6 (continued)

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Discharge pipe, 8"	Labor	PVC plastic, Schedule 40	\$/yd.	31.0	19.5	40.6	35.4
Discharge pipe, 8"	Materials	PVC plastic, Schedule 40	\$/yd.	24.9	19.2	26.4	23.4
Diversion ditch, construction	Installation	Construction and maintenance repair	\$/yd.^{3}	2.11	1.33	2.76	2.38
Drilled holes, 2.5"	Materials/installation	Drilled and cased with pipe	\$/yd.	16.7	10.6	21.9	19.1
Drilled holes, 6"	Materials/installation	Drilled and cased with pipe	\$/yd.	20.3	14.2	24.1	21.1
Drill rig	Rental (Equip./labor)	Crew and light duty rig, and grading	\$/day	400	280	470	420
Excavation, drainage trench	Labor	Use backhoe loader	\$/yd.^{3}	2.01	1.29	2.66	2.28
Excavation, drainage trench	Materials	Use backhoe loader	\$/yd.^{3}	1.22	0.91	1.29	1.14
Excavation, grading, soil	Labor	Excavation/grading, soil, common borrow, 1000 ft (305 m.) haul	\$/yd.^{3}	0.17	0.11	0.22	0.19
Excavation/grading, soil	Equipment	Excavation/grading, soil, common borrow, 1000 ft (305 m.) haul	\$/yd.^{3}	0.58	0.58	0.58	0.58
Excavation, grading, and recontouring of site	Labor	300 ft (90 m.) haul, dozer and truck	\$/yd.^{3}	0.28	0.17	0.36	0.32
Excavation, grading, and recontouring of site	Equipment	300 ft (90 m.) haul, dozer and truck	\$/yd.^{3}	1.03	1.03	1.03	1.03
Exploratory boring	Materials/installation	Test strata in or below landfill, and to apply chemical injection, 4 in. (0.03 m.) diameter holes	\$/yd.	17.9	12.5	21.1	18.6
Flow meters, 6"	Materials/installation	Measures rate of flow of landfill gas to blower	\$/each	880	550	1,150	1,003
Flow me[illegible]s, 8"	Materials/installation	Measures rate of flow of landfill gas to blower	\$/each	1,040	650	1,360	1,180
Geotechnical investigation	Labor/materials	Includes exploratory holes, surveying, mobilization, drilling addition, pump test, and report	\$/site	5,500	3,850	6,520	5,720
Gravel	Labor	One dozer operator, one truck driver	\$/yd.^{3}	1.88	1.19	2.47	1.96
Gravel	Materials	3/4" screened gravel	\$/yd.^{3}	5.47	4.21	5.80	5.70
Grout curtain	Labor	Two grid - pherolic resin (also for grout bottom seal)	\$/yd.^{3}	199	125	261	227
Grout curtain	Materials	Two grid - pherolic resin (also for grout bottom seal)	\$/yd.^{3}	42.7	32.9	45.3	40.1

TABLE A-6 (continued)

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Header pipe, 8"	Materials	PVC Schedule 40	$/yd.	24.9	19.2	26.4	23.4
Header pipe, 8"	Installation	PVC Schedule 40	$/yd.	31.0	19.5	40.6	35.4
Hydroseeding	Labor	Includes seed and soil supplements	$/acre	69.1	43.5	90.5	78.8
Hydroseeding	Materials	Includes seed and soil supplements	$/acre	355	273	376	333
Hydroseeding	Equipment	Includes seed and soil supplements	$/acre	50	50	50	50
Liner	Labor/materials	30 mil., bracketed with heavyweight geotextile fabric, Hypalon	$/yd.^{2}	5.22	3.65	6.19	5.43
Materials testing	Materials/installation	For costing, see "Exploratory Boring"					
Moisture traps	Materials/installation	Removes water from gas control system	$/each	480	335	570	500
Monitoring equipment	Equipment	Gas detection instrumentation to monitor gas control systems (MSA Model 53 Gascope)	$/each	500	500	500	500
Monitoring wells, gas	Materials	0.5" (1.3 cm.), 12 ft (3.6 m.) deep, for landfill gas monitoring	$/yd.	1.22	0.94	1.29	1.15
Monitoring wells, gas	Installation	0.5" (1.3 cm.), 12 ft (3.6 m.) deep, for landfill gas monitoring	$/yd.	8.03	5.05	10.51	9.15
Mulching	Labor	Hay mulching	$/acre	34.5	21.7	45.2	39.3
Mulching	Materials	Hay mulching	$/acre	85.00	65.4	90.1	79.9
Mulching	Equipment	Hay mulching	$/acre	23.2	23.2	23.2	23.2
Pipe, PVC (elbows), 6"	Materials	90° fitting	$/each	27.0	20.8	28.6	25.4
Pipe, PVC (elbows), 6"	installation	90° fitting	$/each	28.0	17.6	36.7	31.9
Pipe, PVC (elbows), 8"	Materials	90° fitting	$/each	52.0	40.0	55.1	48.9
Pipe, PVC (elbows), 8"	Installation	90° fitting	$/each	39.0	24.6	51.1	44.5
Pipe, PVC (Tees), 6"	Materials	T-fittings for gas wells	$/each	37.0	28.5	39.2	34.8
Pipe, PVC (Tees), 6"	Installation	T-fittings for gas wells	$/each	46.0	29.0	60.3	52.4
Pipe, PVC (Tees), 8"	Materials	T-fittings for gas wells	$/each	75.0	57.7	79.5	70.5
Pipe, PVC (Tees), 8"	Installation	T-fittings for gas wells	$/each	59.0	37.2	77.3	67.3
Pipe, PVC, laterals, 8"	Materials	For gas extraction wells, Schedule 40	$/yd.	24.9	19.2	26.4	23.4

TABLE A-6 (continued)

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Pipe, PVC, laterals, 8"	Installation	For gas extraction wells, Schedule 40	$/yd	31.0	19.5	40.6	35.4
Pipe, PVC, laterals, 12"	Materials	For gas extraction wells, Schedule 80	$/yd.	112	86.1	118	105
Pipe, PVC, laterals, 12"	Installation	For gas extraction wells, Schedule 80	$/yd.	14.1	10.9	14.9	13.2
Pipe, PVC, risers, 4"	Materials	For gas extraction wells, Schedule 40	$/yd.	8.33	6.42	8.83	7.83
Pipe, PVC, risers, 4"	Installation	For gas extraction wells, Schedule 40	$/yd.	20.0	12.6	26.2	22.8
Pipe, PVC, risers 6"	Materials	For gas extraction wells, Schedule 40	$/yd.	14.9	11.5	15.8	14.6
Pipe, PVC, risers 6"	Installation	For gas extraction wells, Schedule 40	$/yd.	23.4	14.8	30.7	26.7
Pump, centrifugal	Equipment/installation	3/4 HP pump	$/each	1,600	1,600	1,600	1,600
Pump, submersible	Labor	1 HP - 4", submersible	$/each	344	220	450	390
Pump, submersible	Materials	1 HP - 4" submersible	$/each	424	330	450	400
Recharge trench	Materials/installation	Excavation of trench	$/yd.^{3}	1.22	0.85	1.44	1.26
Sand	Materials/installation	For well point casing backfill	$/bag	5.80	4.06	6.87	6.03
Sheet piling	Materials	Steel sheet, PMA-22 (22 lbs/ft^2)	$/ton	460	354	488	433
Sheet piling	Installation	Install steel sheet, PMA-22 (22 lbs/ft^2)	$/ton	90.8	57.2	119	103
Slurry trench excavation	Materials/installation	Includes installation of bentonite slurry	$/yd.^{3}	35.0	24.5	41.4	36.4
Spread excavated material	Labor	One equipment operator, five laborers	$/yd.^{3}	0.16	0.10	0.19	0.17
Spread excavated material	Equipment	Spread by dozer, no compaction	$/yd.^{3}	0.39	0.39	0.39	0.39
Surface seal, bituminous concrete	Installation	3" (0.08 m.) thick cap	$/yd.^{2}	0.88	0.55	1.15	1.01
Surface seal, bituminous concrete	Materials	3" (0.08 m.) thick cap	$/yd.^{2}	2.52	1.94	2.67	2.37
Surface seal, clay cap	Materials/installation	6" (15-cm.) clay cap, includes 18" (46-cm.) soil cover	$/yd.^{2}	3.98	2.89	5.29	4.53
Surface seal, clay cap	Materials/installation	18" (46-cm.) clay cap, includes 18" (46-cm.) soil cover	$/yd.^{2}	5.11	3.73	6.79	5.83
Surface seal, fly ash cap	Materials/installation	12" (30-cm.) fly ash, includes 18" (46-cm.) soil cover	$/yd.^{2}	3.84	2.81	5.11	4.38

TABLE A-6 (continued)

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Surface seal, fly ash cap	Materials/installation	24" (60-cm.) fly ash cap, includes 18" (46-cm.) soil cover	$\$/\text{yd.}^2$	5.20	3.71	6.91	5.93
Surface seal, lime-stabilized cap	Materials/installation	5" (13-cm.) lime-stabilized cap, includes 18" (46-cm.) soil cover	$\$/\text{yd.}^2$	4.99	4.33	6.64	5.69
Surface seal, PVC membrane cap	Materials/installation	30-mil PVC membrane cap, includes 18" (46-cm.) soil cover	$\$/\text{yd.}^2$	8.94	8.03	11.	10.2
Surface seal, soil-cement cap	Materials/installation	5" (13-cm.) soil-cement cap, includes 18" (46-cm.) soil cover	$\$/\text{yd.}^2$	4.99	4.33	6.64	5.69
Surveying	Labor	Labor cost/day, establish surface topographic profile	$/day	220	150	260	230
Tipping fees	Unit costs	Dumping and grading wastes at new site	$/ton	100	100	100	100
Transportation	Labor/equipment	30-ton dump truck/driver, based on one-way hauling distance, return trip included	$/ton-mi.	0.070	0.044	0.093	0.080
Transportation	Labor/equipment	15-ton dump truck/driver, based on one-way hauling distance, return trip included	$/ton-mi.	0.080	0.050	0.106	0.091
Treatment system	Unit costs	Typical costs - interpolated @ 0.12 MGD (440,000 l./d)	$/each	580K	406K	687K	603K
Trench excavation	Labor	One equipment operator/one laborer	$\$/\text{yd.}^3$	0.17	0.13	0.27	0.24
Trench excavation	Equipment	Tractor or hydraulic backhoe to excavate trench, sloped 1/2 to 1	$\$/\text{yd.}^3$	0.88	0.88	0.88	0.88
Well points, 2.5" (6.4 cm.) dia.	Materials/installation	PVC, 25 feet (7.6 m.)	$/yd.	54.0	37.8	64.0	56.1
Wellpoint fittings	Materials/installation	Fittings and accessories	$/well	12.0	8.40	14.2	12.5

TABLE A-7. LANDFILL O&M COST COMPONENTS - ENGLISH UNITS

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Chemicals	Materials	Wastewater/leachate treatment plant chemicals	$/gal./day (influent)	0.095	0.095	0.095	0.095
Electricity	Power costs	For water treatment plant, extraction, injection, and gas control well/pumps	$/kwh	0.05	0.05	0.05	0.05
Grubbing	Labor/equipment	Assume annual grubbing (clearing) of brush	\$/yd.^{2}	0.16	0.10	0.21	0.18
Maintenance/repair, diversion ditch	Installation	Assume diversion ditch needs rebuilding 2 times a year after major storms	\$/yd.^{3}	2.10	1.32	2.75	2.40
Monitoring	Labor	For gas monitoring at active and passive gas control installations	$/hr.	12.5	7.88	16.6	14.2
Monitoring (analysis)	Laboratory costs	For ground water/leachate monitoring from monitoring wells	$/sample	330	330	330	330
Monitoring (sampling)	Labor	For ground water/leachate monitoring from monitoring wells	$/hr.	12.5	7.88	16.6	14.2
Grass mowing	Labor/materials	Use 58" power ride mower, one operator	$/acre	38	27	45	40
Operating cost	Labor	For water treatment plant operating personnel	$/hr.	10.0	6.30	13.10	11.4
Operating cost	Labor	For gas collection system operating personnel	$/hr.	15.0	9.45	19.9	17.1
Refertilization	Labor/materials	Assume refertilization once per year	$/acre	138	100	160	140
Water	Materials	Industrial process water	$/103 gal.	3.50	3.50	3.50	3.50

TABLE A-8. SURFACE IMPOUNDMENT CAPITAL COST COMPONENTS - METRIC UNITS

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Area preparation	Labor	For area preparation, rake and clean up, average	$/m.^{2}	Dodge 1980	0.074	0.047	0.096	0.084
Area preparation	Equipment	For area preparation, rake and clean up, average	$/m.^{2}	Dodge 1980	0.022	0.022	0.022	0.022
Bentonite, delivered	Materials/shipping	Shipment of bentonite by rail near job site, includes materials and delivery	$/tonne	Burlington Northern 1980		66.4	177	166.
Cement pipe, 6"	Materials	Class 4000, perforated, asbestos	$/m.	Means 1980	8.00	6.16	8.48	7.52
Cement pipe, 6"	Installation	Class 4000, perforated, asbestos	$/m.	Means 1980	3.10	1.95	4.06	3.53
Discharge trench	Labor	Including backfill 3 ft (1 m.) deep	$/m.^{3}	Means 1980	1.97	1.24	2.58	2.23
Discharge trench	Equipment	Including backfill 3 ft (1 m.) deep	$/m.^{3}	Means 1980	1.57	1.57	1.57	1.57
Diversion ditch, construction	Installation	Construction and maintenance/repair	$/m.^{3}	Means 1980	2.78	1.75	3.63	3.13
Drilled holes, 6"	Materials/installation	Drilled and cased with pipe	$/m.	Means 1980	22.3	15.6	26.4	23.2
Drill rig	Rental (Equipment/labor)	Crew and light-duty rig	$/day	Means 1980	400	280	470	420
Excavation	Labor	One equipment operator	$/m.^{3}	Means 1980	0.16	0.10	0.21	0.18
Excavation	Equipment	Front end loader	$/m.^{3}	Means 1980	0.65	0.65	0.65	0.65
Excavating/grading, soil	Labor	Common borrow (earth), 1000 ft (305 m.) haul	$/m.^{3}	Dodge 1980	0.22	0.14	0.29	0.25
Excavating/grading, soil	Equipment	Common borrow (earth), 1000 ft (305 m.) haul	$/m.^{3}	Dodge 1980	0.76	0.76	0.76	0.76
Geotechnical investigation	Unit costs	Includes surveying, test borings, equipment, mobilization, monitoring wells, pump tests, report	$/each	SCS 1980	14,500	9,500	19,500	16,900
Geotechnical investigation	Unit costs	Slurry wall testing	$/each	SCS 1980	2,000	1,260	2,620	2,260
Gravel	Labor/installation	3/4" screened gravel, one dozer operator, one truck driver	$/m.^{3}	Means 1980	2.48	1.56	3.25	2.58
Gravel	Materials	3/4" screened gravel, one dozer operator, one truck driver	$/m.^{3}	Means 1980	7.20	5.54	7.63	7.50
Grout curtain	Labor	Chemical grout, phenolic resin, 2-grid	$/m.^{3}	Means 1980	262	165	343	298

TABLE A-8 (continued)

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Grout curtain	Materials	Chemical grout, phenolic resin, 2-grid	\$/m.^{3}	Means 1980	56.2	43.3	59.6	52.8
Header and discharge pipe, 8"	Materials	PVC class 150 pipe, laid in trench	\$/m.	Means 1980	24.2	18.6	25.6	22.7
Header and discharge pipe, 8"	Installation	PVC class 150 pipe, laid in trench	\$/m.	Means 1980	9.61	6.05	12.6	10.9
Hydroseeding	Labor	Seed and soil supplements/ amendments	\$/m.^{2}	Dodge 1980	0.0171	0.0108	0.0224	0.0195
Hydroseeding	Materials	Seed and soil supplements/ amendments	\$/m.^{2}	Dodge 1980	0.0877	0.0675	0.0929	0.0824
Hydroseeding	Equipment	Hydroseeding	\$/m.^{2}	Dodge 1980	0.0124	0.0124	0.0124	0.0124
Mulching	Labor	Mulching hay	\$/m.^{2}	Dodge 1980	0.0085	0.0054	0.0112	0.0097
Mulching	Materials	Mulching hay	\$/m.^{2}	Dodge 1980	0.0210	0.0162	0.0223	0.0197
Mulching	Equipment	Mulching hay	\$/m.^{2}	Dodge 1980	0.0057	0.0057	0.0057	0.0057
Pump, centrifugal	Equipment/installation	3/4 HP pump	\$/each	Means 1980	1,600	1,600	1,600	1,600
Pump, submersible	Labor/installation	1 HP, 4", including wiring	\$/each	Means 1980	344	220	450	390
Pump, submersible	Materials	1 HP, 4", including wiring	\$/each	Means 1980	424	330	450	400
Sheet piling	Labor/equipment/ installation	PMA-22 steel sheet piling (22 lbs/ ft^2)	\$/tonne	Means 1980	100	63	131	114
Sheet piling	Materials	PMA-22 steel sheet piling (22 lbs/ ft^2)	\$/tonne	Means 1980	507	390	537	476
Slurry wall, installation	Installation	Install slurry compound in excavated trench	\$/m.^{3}	Means 1980	45.9	32.2	54.5	47.8
Slurry wall testing	Unit cost	See "Geotechnical Investigation, Slurry wall testing"						
Soil compacting	Labor	With sheepsfoot roller	\$/m.^{3}	Means 1980	0.63	0.40	0.83	0.71
Soil compacting	Equipment	With sheepsfoot roller	\$/m.^{3}	Means 1980	0.86	0.86	0.86	0.86
Sump	Labor/equipment	16 ft (5 m.) deep x 8" (20 cm.) thick concrete, cast in place	\$/each	Means 1980	820	516	1,074	926
Sump	Materials	16 ft (5 m.) deep x 8" (20 cm.) thick concrete, cast in place	\$/each	Means 1980	750	577	795	705

TABLE A-8 (continued)

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Surface seal, bituminous concrete	Labor/equipment	3" (0.08 m.) thick cap	$\$/\mathrm{m.}^2$	Means 1980	1.05	0.72	1.24	1.09
Surface seal, bituminous concrete	Materials	3" (0.08 m.) thick cap	$\$/\mathrm{m.}^2$	Means 1980	3.00	2.31	3.18	2.82
Surface seal, clay cap	Materials/installation	6" (15-cm.) clay cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	4.82	3.50	6.41	5.49
Surface seal, clay cap	Materials/installation	18" (46-cm.) clay cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	6.18	4.51	8.22	7.06
Surface seal, fly ash cap	Materials/installation	12" (30-cm.) fly ash cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	4.60	3.40	6.18	5.24
Surface seal, fly ash cap	Materials/installation	24" (60-cm.) fly ash cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	6.28	4.49	8.36	7.15
Surface seal, lime-stabilized cap	Materials/installation	5" (13-cm.) lime-stabilized cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	6.05	5.24	8.04	6.90
Surface seal, PVC membrane cap	Materials/installation	30-mil PVC membrane cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	10.8	9.72	14.4	12.3
Surface seal, soil-cement cap	Materials/installation	5" (13-cm.) soil-cement cap, includes 18" (46-cm.) soil cover	$\$/\mathrm{m.}^2$	Martin 1978	6.05	5.24	8.04	6.90
Surveying	Labor	Labor costs/day	\$/day	Means 1980	220	150	260	230
Tipping fee	Unit costs	Fee paid at secure landfill	\$/tonne	SCS 1979	110	110	110	110
Transportation	Labor/equipment	30-ton dump truck/driver, based on one-way hauling distance, return trip included	\$/tonne-km	SCS 1981	0.096	0.060	0.128	0.109
Transportation	Labor/equipment	15-ton dump truck/driver, based on one-way hauling distance, return trip included	\$/tonne-km	SCS 1981	0.110	0.069	0.145	0.125
Treatment plant	Unit costs	Costs interpolated from Dodge Guide 1980, with SCS estimate	\$/l./day	Dodge 1980	0.89	0.70	1.18	1.04
Trench excavation	Labor	16 ft (5 m.) deep x 3 ft (1 m.) wide, one equipment operator, one laborer	$\$/\mathrm{m.}^3$	Means 1980	0.22	0.17	0.35	0.31
Trench excavation	Equipment	16 ft (5 m.) deep x 3 ft (1 m.) wide, backhoe excavator, sloped 1/2:1	$\$/\mathrm{m.}^3$	Means 1980	1.16	1.16	1.16	1.16
Well fittings, 8"	Materials	PVC	\$/well	Means 1980	127	97.8	134.6	119.4
Well fittings, 8"	Installation	PVC	\$/well	Means 1989	98	61.4	128.4	110.7
Well points, 2.5"	Materials/installation	16 ft (4.9 m.) long	\$/m.	Dodge 1980	59.3	40	70	62
Wellpoint fittings	Unit costs	Fittings and accessories	\$/well	Dodge 1980	12.0	8.40	14.2	12.5

TABLE A-9. SURFACE IMPOUNDMENT O&M COST COMPONENTS - METRIC UNITS

Component	Subcomponent	Definition	Metric Units	Source	Source Cost	Low	High	Newark
Chemicals	Materials	Wastewater/leachate treatment plant chemicals	\$/l./day (influent)	SCS 1980	0.025	0.025	0.025	0.025
Electricity	Power costs	For water treatment plant or extraction, injection, and gas control wells/pumps	\$/kwh	SCS 1980	0.05	0.05	0.05	0.05
Refertilizing	Labor/materials	Assume fertilizing once/year	\$/m.^{2}	Dodge 1980	0.0060	0.0046	0.0064	0.0056
Grass mowing	Labor/equipment	Assume grass mowing 6 times/year, minimum \$10 per visit	\$/m.^{2}	Dodge 1980	0.0015	0.00097	0.002	0.0017
Grubbing	Labor/equipment	Assume annual grubbing (clearing) of brush	\$/m.^{2}	Dodge 1980	0.19	0.12	0.25	0.22
Maintenance/repair, diversion ditch	Installation	Assume twice annual ditch repair	\$/m.^{3}	Means 1980	2.78	1.75	3.63	3.16
Monitoring (analysis)	Laboratory costs	For ground water/leachate monitoring from monitoring wells	\$/sample	SCS 1980	330	330	330	330
Monitoring (sampling)	Labor	For ground water/leachate monitoring from monitoring wells	\$/hr.	SCS 1980	12.5	7.88	16.6	14.2
Operator personnel	Labor	For operation of water treatment plant and sampling for monitoring	\$/hr.	SCS 1980	12.6	7.92	16.3	14.3

TABLE A-10. SURFACE IMPOUNDMENT CAPITAL COST COMPONENTS - ENGLISH UNITS

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Area preparation	Labor	For area preparation, rake and clean up, average	$/yd.^{2}	0.062	0.039	0.081	0.070
Area preparation	Equipment	For area preparation, rake and clean up, average	$/yd.^{2}	0.019	0.019	0.019	0.019
Bentonite, delivered	Materials/shipping	Shipment of bentonite by rail near job site, includes materials and delivery	$/ton		60.4	161	159
Cement pipe, 6"	Materials	Class 4000, perforated, asbestos	$/yd.	7.28	5.61	7.72	6.84
Cement pipe, 6"	Installation	Class 4000, perforated, asbestos	$/yd.	2.82	1.77	3.69	3.21
Discharge trench	Labor	Including backfill 3 ft (1 m.) deep	$/yd.^{3}	1.50	0.94	1.96	1.69
Discharge trench	Equipment	Including backfill 3 ft (1 m.) deep	$/yd.^{3}	1.10	1.10	1.10	1.10
Diversion ditch, construction	Installation	Construction and maintenance/repair	$/yd.^{3}	2.11	1.33	2.76	2.38
Drilled holes, 6"	Materials/installation	Drilled and cased with pipe	$/yd.	20.3	14.2	24.0	21.1
Drill rig	Rental (Equipment/ labor)	Crew and light-duty rig	$/day	400	280	470	420
Excavation	Labor	One equipment operator	$/yd.^{3}	0.12	0.08	0.16	0.14
Excavation	Equipment	Front end loader	$/yd.^{3}	0.49	0.49	0.49	0.49
Excavating/grading, soil	Labor	Common borrow (earth), 1000 ft (305 m.) haul	$/yd.^{3}	0.17	0.11	0.22	0.19
Excavating/grading, soil	Equipment	Common borrow (earth), 1000 ft (305 m.) haul	$/yd.^{3}	0.58	0.58	0.58	0.58
Geotechnical investigation	Unit costs	Includes surveying, test borings, equipment, mobilization, monitoring wells, pump tests, report	$/site	14,500	9,500	19,500	16,900
Geotechnical investigation	Unit costs	Slurry wall testing	$/each	2,000	1,260	2,620	2,260
Gravel	Labor/installation	3/4" screened gravel, one dozer operator, one truck driver	$/yd.^{3}	1.88	1.19	2.47	1.96
Gravel	Materials	3/4" screened gravel, one dozer operator, one truck driver	$/yd.^{3}	5.47	4.21	5.80	5.70
Grout curtain	Labor	Chemical grout, phenolic resin, 2-grid	$/yd.^{3}	199	125	261	227

TABLE A-10 (continued)

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Grout curtain	Materials	Chemical grout, phenolic resin, 2-grid	$/yd.^3$	47.7	32.9	45.3	40.1
Header and discharge pipe, 8"	Materials	PVC class 150 pipe, laid in trench	$/yd.	22.0	17.0	23.3	20.7
Header and discharge pipe, 8"	Installation	PVC class 150 pipe, laid in trench	$/yd.	8.75	5.51	11.5	9.88
Hydroseeding	Labor	Seed and soil supplements/amendments	$/yd.^2$	0.0143	0.0090	0.0187	0.0163
Hydroseeding	Materials	Seed and soil supplements/amendments	$/yd.^2$	0.0733	0.0565	0.0777	0.0689
Hydroseeding	Equipment	Hydroseeding	$/yd.^2$	0.0103	0.0103	0.0103	0.0103
Mulching	Labor	Mulching hay	$/yd.^2$	0.0071	0.0045	0.0093	0.0081
Mulching	Materials	Mulching hay	$/yd.^2$	0.0175	0.0135	0.0186	0.0165
Mulching	Equipment	Mulching hay	$/yd.^2$	0.0048	0.0048	0.0048	0.0048
Pump, centrifugal	Equipment/installation	3/4 HP pump	$/each	1600	1600	1600	1600
Pump, submersible	Labor/installation	1 HP, 4", including wiring	$/each	344	220	450	390
Pump, submersible	Materials	1 HP, 4", including wiring	$/each	424	330	450	400
Sheet piling	Labor/equipment/installation	PMA-22 steel sheet piling (22 lbs/ft^2)	$/ton	90.8	57.2	119	103
Sheet piling	Materials	PMA-22 steel sheet piling (22 lbs/ft^2)	$/ton	460	354	480	433
Slurry wall, installation	Installation	Install slurry compound in excavated trench	$/yd.^3$	35.1	24.6	41.7	36.5
Slurry wall testing	Unit cost	See "Geotechnical Investigation, Slurry wall testing"					
Soil compacting	Labor	With sheepsfoot roller	$/yd.^3$	0.48	0.30	0.63	0.54
Soil compacting	Equipment	With sheepsfoot roller	$/yd.^3$	0.65	0.65	0.65	0.65
Sump	Labor/equipment	16 ft (5 m.) deep x 8" (20 cm.) thick concrete, cast in place	$/each	820	517	1,074	926
Sump	Materials	16 ft (5 m.) deep x 8" (20 cm.) thick concrete, cast in place	$/each	750	577	795	705

TABLE A-10 (continued)

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Surface seal, bituminous concrete	Labor/equipment	3" (0.08 m.) thick cap	\$/yd.^{2}	0.86	0.60	1.04	0.92
Surface seal, bituminous concrete	Materials	3" (0.08 m.) thick cap	\$/yd.^{2}	2.52	1.94	2.67	2.37
Surface seal, clay cap	Materials/installation	6" (15-cm.) clay cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	3.98	2.89	5.29	4.54
Surface seal, clay cap	Materials/installation	18" (46-cm.) clay cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	5.11	3.73	6.79	5.83
Surface seal, fly ash cap	Materials/installation	12" (30-cm.) fly ash cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	3.84	2.81	5.11	4.38
Surface seal, fly ash cap	Materials/installation	24" (60-cm.) fly ash cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	5.20	3.71	6.91	-5.93
Surface seal, lime-stabilized cap	Materials/installation	5" (13-cm.) lime-stabilized cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	4.99	4.33	6.64	5.69
Surface seal, PVC membrane cap	Materials/installation	30-mil PVC membrane cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	8.94	8.03	11.9	10.2
Surface seal, soil-cement cap	Materials/installation	5" (13-cm.) soil-cement cap, includes 18" (46-cm.) soil cover	\$/yd.^{2}	4.99	4.33	6.64	5.69
Surveying	Labor	Labor costs/day	\$/day	220	150	260	230
Tipping fee	Unit costs	Fee paid at secure landfill	\$/ton	100	100	100	100
Transportation	Labor/equipment	30-ton dump truck/driver, based on one-way hauling distance, return trip included	\$/ton-mi.	0.070	0.044	0.093	0.080
Transportation	Labor/equipment	15-ton dump truck/driver, based on one-way hauling distance, return trip included	\$/ton-mi.	0.080	0.050	0.106	0.091
Treatment plant	Unit costs	Costs interpolated from Dodge Guide 1980, with SCS estimate	\$/gpd	3.38	2.65	4.49	3.94
Trench excavation	Labor	16 ft (5 m.) deep x 3 ft (1 m.) wide, one equipment operator, one laborer	\$/yd.^{3}	0.17	0.13	0.27	0.24
Trench excavation	Equipment	16 ft (5 m.) deep x 3 ft (1 m.) wide, backhoe excavator, sloped 1/2:1	\$/yd.^{3}	0.88	0.88	0.88	0.88
Well fittings, 8"	Materials	PVC	\$/well	127	97.8	135	119
Well fittings, 8"	Installation	PVC	\$/well	98.0	61.7	128	111
Well points, 2.5"	Materials/installation	16 ft (4.9 m.) long	\$/yd.	53.8	36.3	63.5	56.3
Wellpoint fittings	Unit costs	Fittings and accessories	\$/well	12.0	8.40	14.2	12.5

TABLE A-11. SURFACE IMPOUNDMENT O&M COST COMPONENTS - ENGLISH UNITS

Component	Subcomponent	Definition	English Units	Source Cost	Low	High	Newark
Chemicals	Materials	Wastewater/leachate treatment plant chemicals	\$/gpd (influent)	0.095	0.095	0.095	0.095
Electricity	Power costs	For water treatment plant or extraction, injection, and gas control wells/pumps	\$/kwh	0.05	0.05	0.05	0.05
Refertilizing	Labor/materials	Assume fertilizing once/year	\$/yd.^{2}	0.0050	0.0039	0.0054	0.0047
Grass mowing	Labor/equipment	Assume grass mowing 6 times/year, minimum \$10 per visit	\$/yd.^{2}	0.0013	0.00081	0.0017	0.0014
Grubbing	Labor/equipment	Assume annual grubbing (clearing) of brush	\$/yd.^{2}	0.13	0.10	0.21	0.18
Maintenance repair/ diversion ditch	Installation	Assume twice annual ditch repair	\$/yd.^{3}	2.11	1.33	2.76	2.38
Monitoring (analysis)	Laboratory costs	For ground water/leachate monitoring from monitoring wells	\$/sample	330	330	330	330
Monitoring (sampling)	Labor	For ground water/leachate monitoring from monitoring wells	\$/hr.	12.5	7.88	16.6	14.2
Operator personnel	Labor	For operation of water treatment plant and sampling for monitoring	\$/hr.	12.6	7.92	16.3	14.3